https://ntrs.nasa.gov/search.jsp?R=20120016551 2019-08-30T23:12:09+00:00Z

Safety and Long-Term Performance of Lithium-ion Pouch Cells

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Background

- Commerical off-the-shelf (COTS) li-ion cells are frequently subjected to a standard set of tests to determine their performance and safety and add them to a database that allows users at NASA-JSC to choose cell designs for specific applications.
- In recent years, Li-ion pouch cell designs are used increasingly in portable equipment applications and are commonly being referred to as lithium polymer cells, although these cells are not of the true polymer types.
- Several Li-ion polymer or pouch cells have been tested at NASA-JSC in the past 15 years and the cells from developed from being low rate (Ultralife, 1998) to medium rates in the 2005 timeframe (Valence, Samsung, Kokam, etc.) to high energy and high rates during the present time.
- Testing of these li-ion polymer cells have shown that long term storage as well as vacuum exposures cause swelling of the pouch.
- Recent test programs at NASA-JSC have focused on testing the li-ion polymer cells for their safety as well as their performance under different rates and temperatures as well as under vacuum and reduced pressure conditions.
- The most recent tests included cells of the following types:

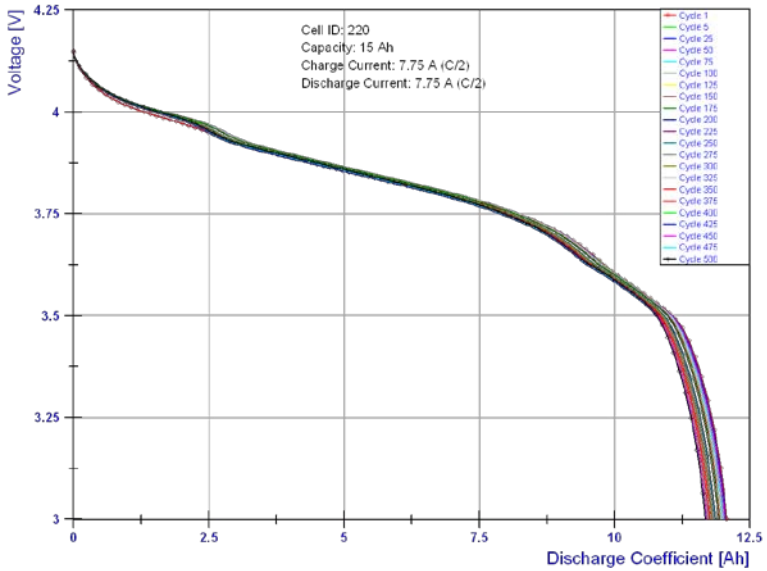
  SKC 15 Ah (high-rate capability)

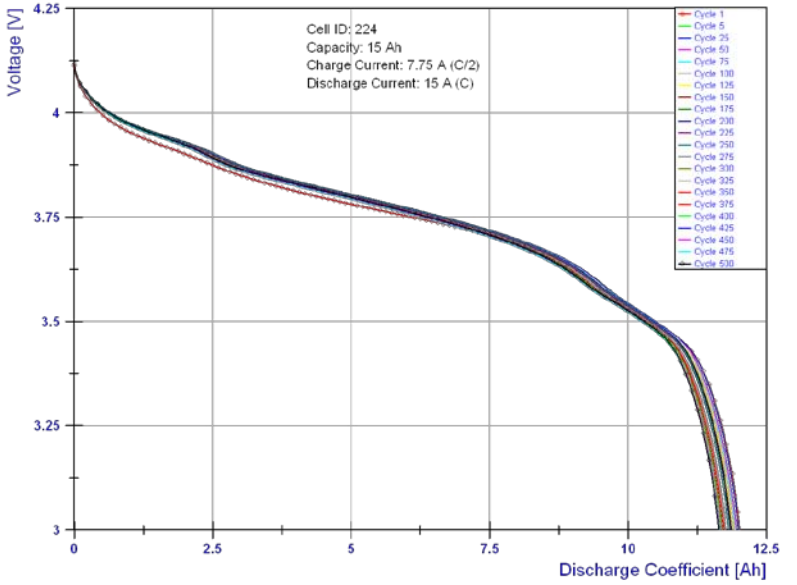
  Tenergy 6 Ah (medium rate medium energy density)

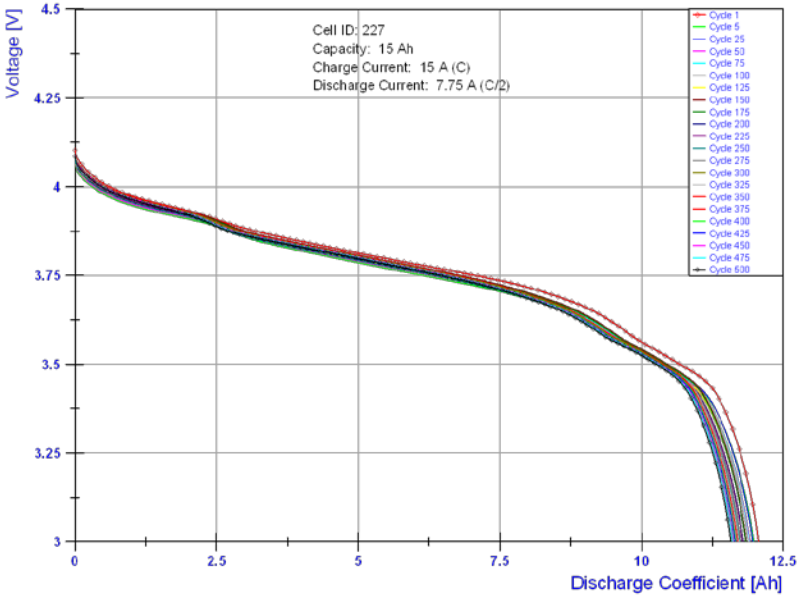
  Altairnano 13 Ah (nanotitanate anode with high rate capabiltiy)

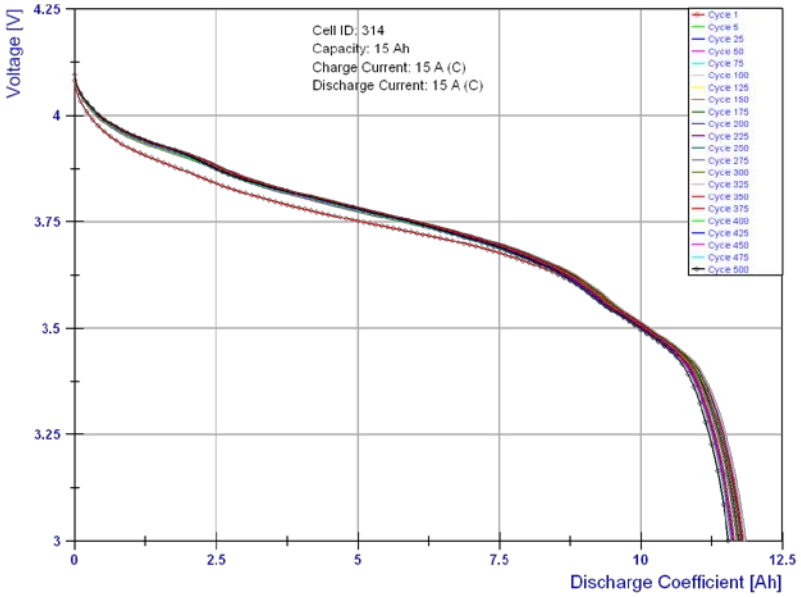
  Wanma 5 Ah (medium rate medium energy density)

SKC 15 Ah Li-ion Performance Tests

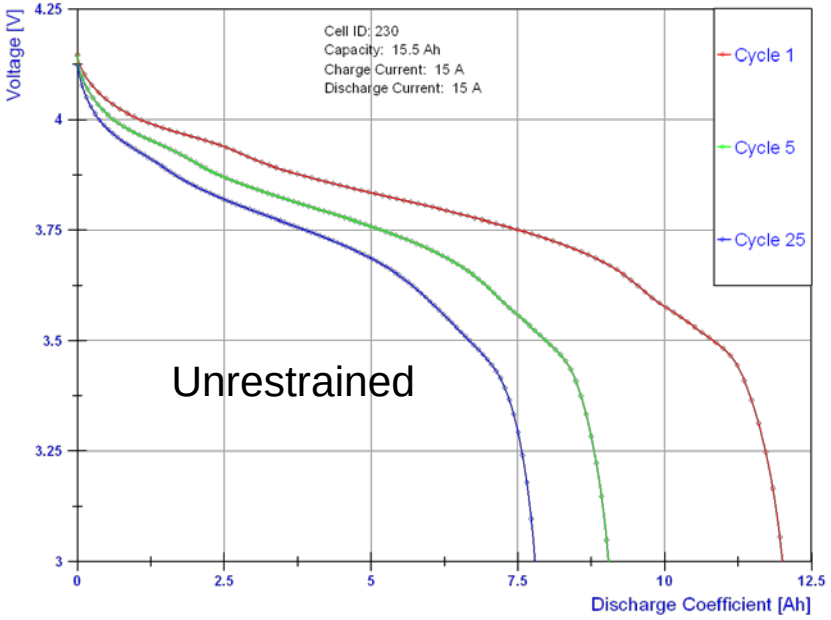






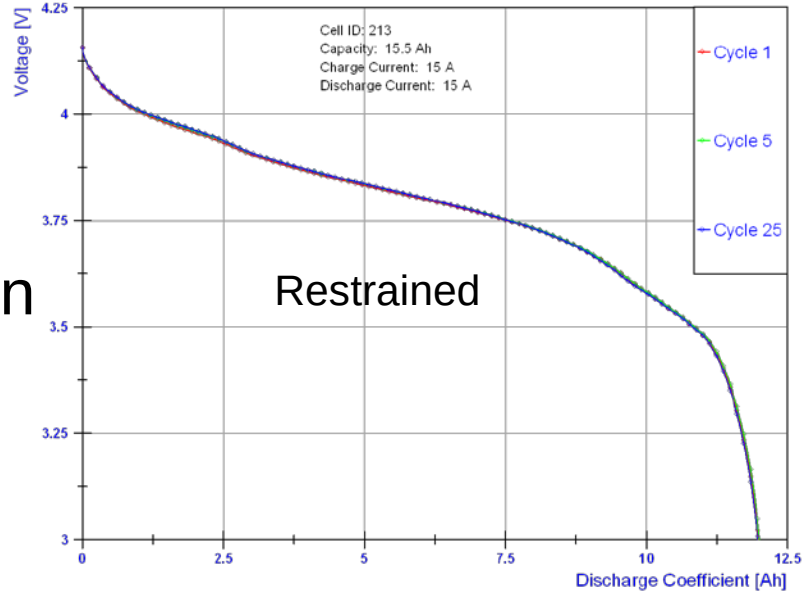


SKC 15 Ah Li-ion Cell Cycling Under Vacuum Environments



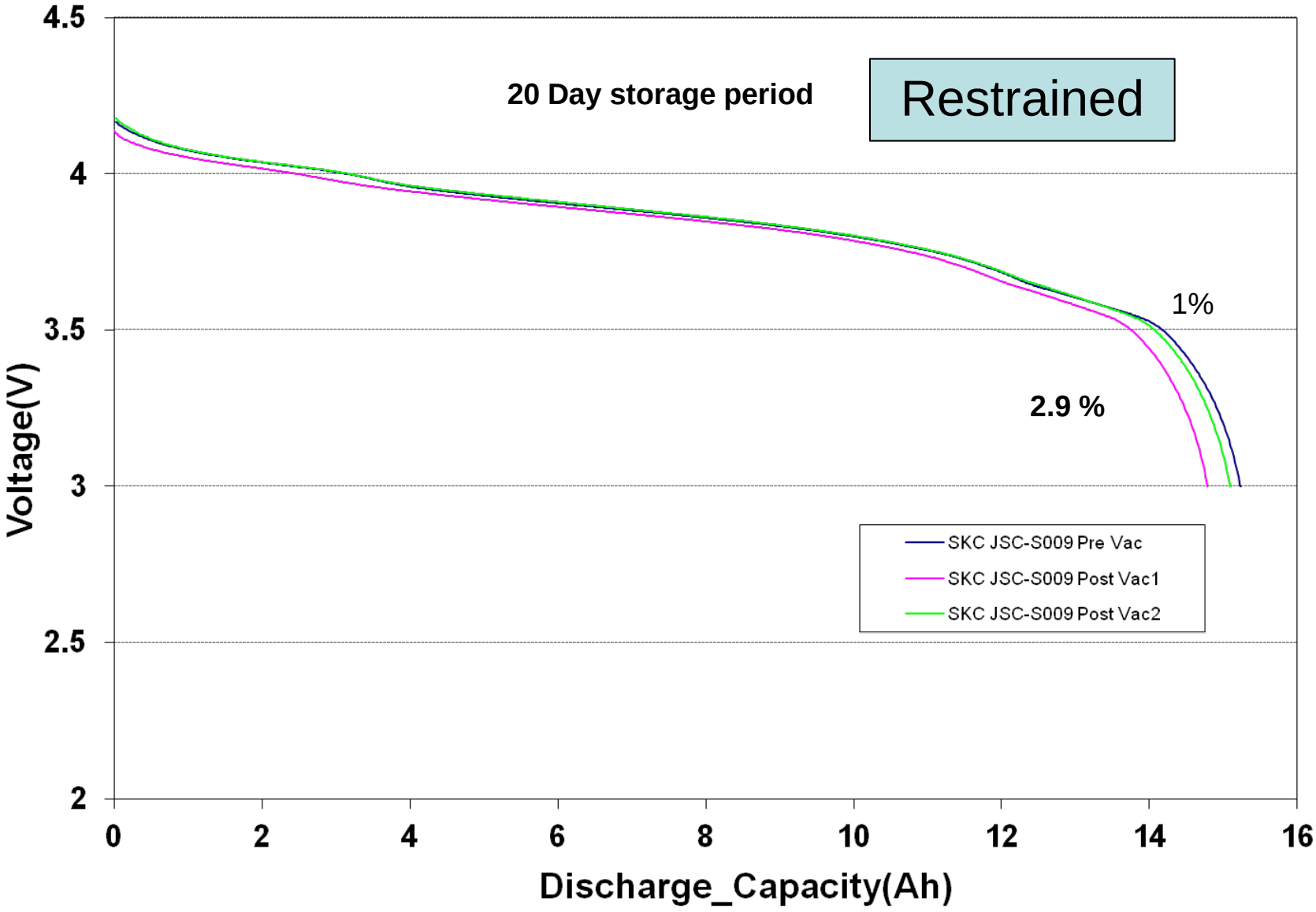
Unrestrained SKC Cell Data

Serial Number	Pre OCV	Post OCV	Pre Capacity	Post Capacity
230	4.069 V	3.097 V	14.93 Ah	14.855 Ah

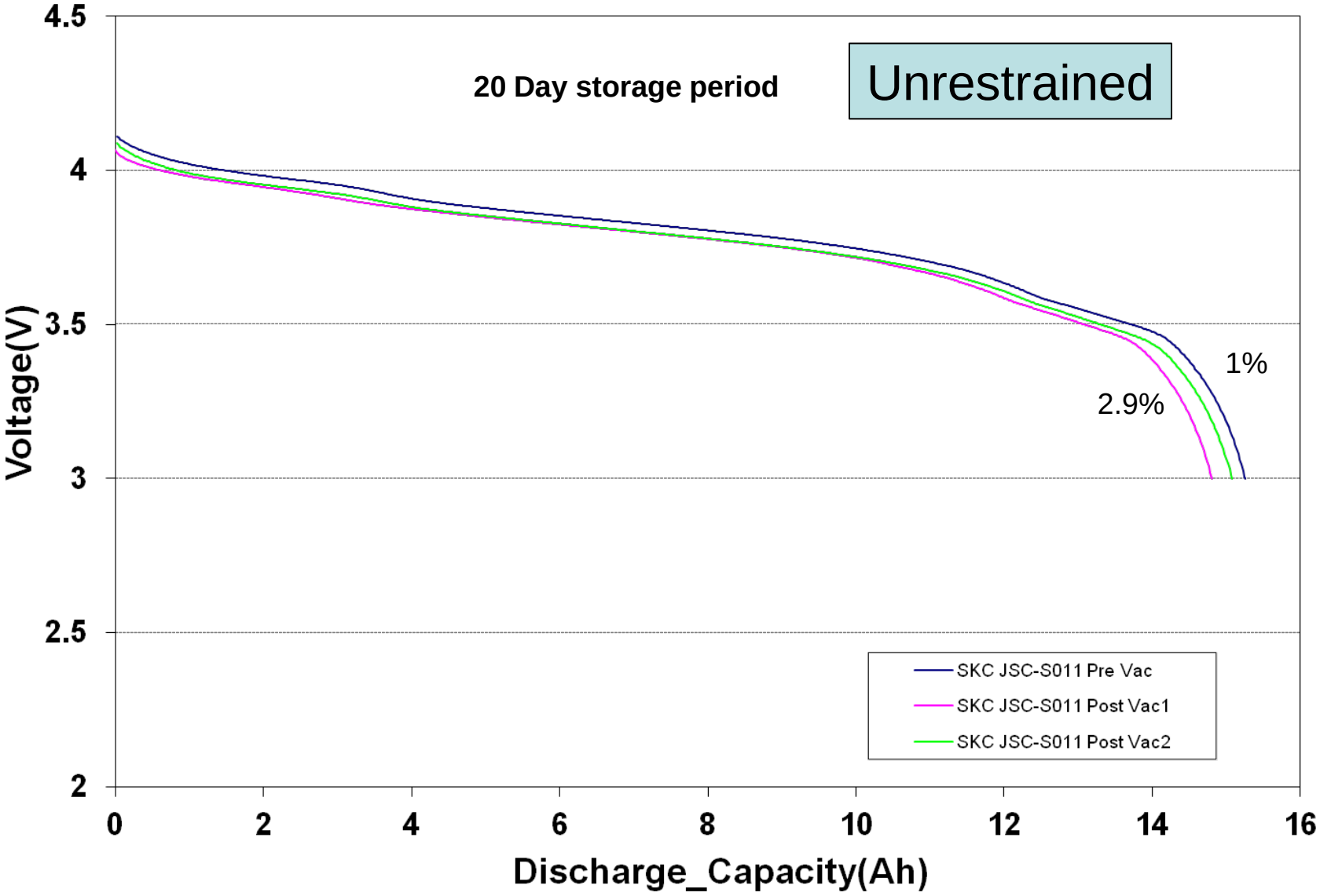


Restrained cells show change in performance under vacuum conditions

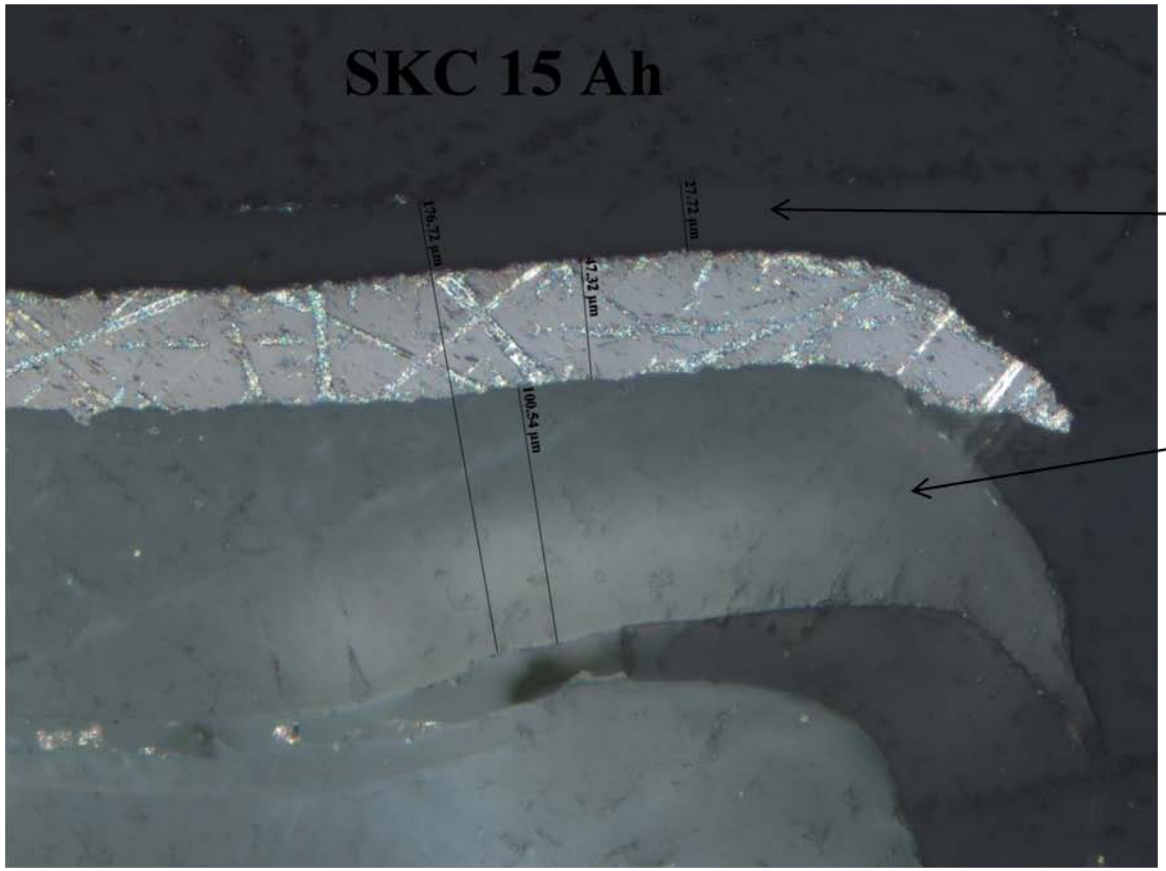
SKC Li-ion Cell Performance After Vacuum Exposure and Storage at Ambient



SKC Li-ion Cell Performance After Vacuum Cycling and Storage at Ambient



Pouch Material Cross-Section



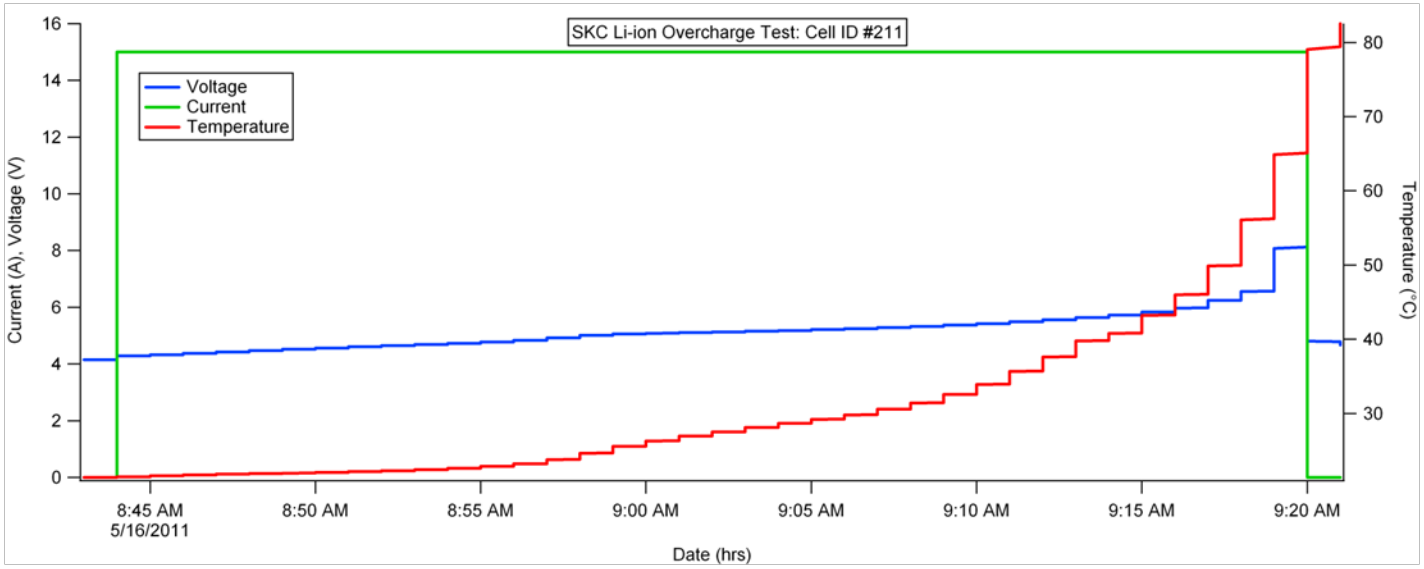
Outside:
Nylon 6

Inside:
Polypropylene

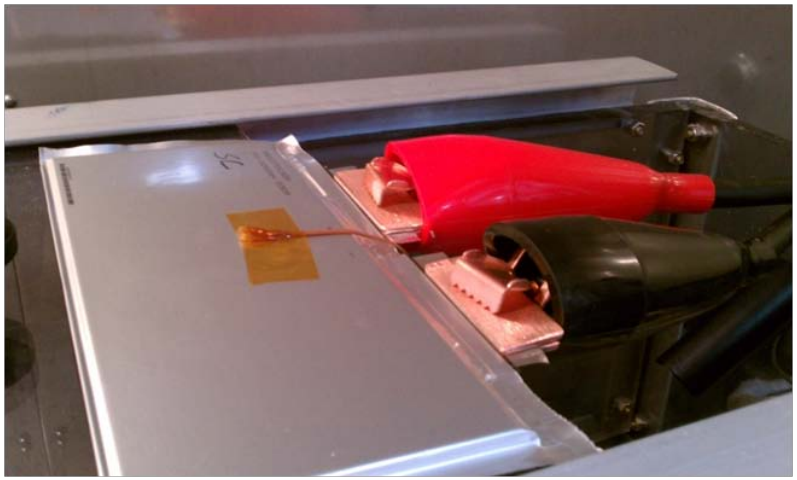
SKC 15 Ah Cell Safety Tests

Overcharge Test
(15 A; 12 V limit; max 6 hours

Cell swelling



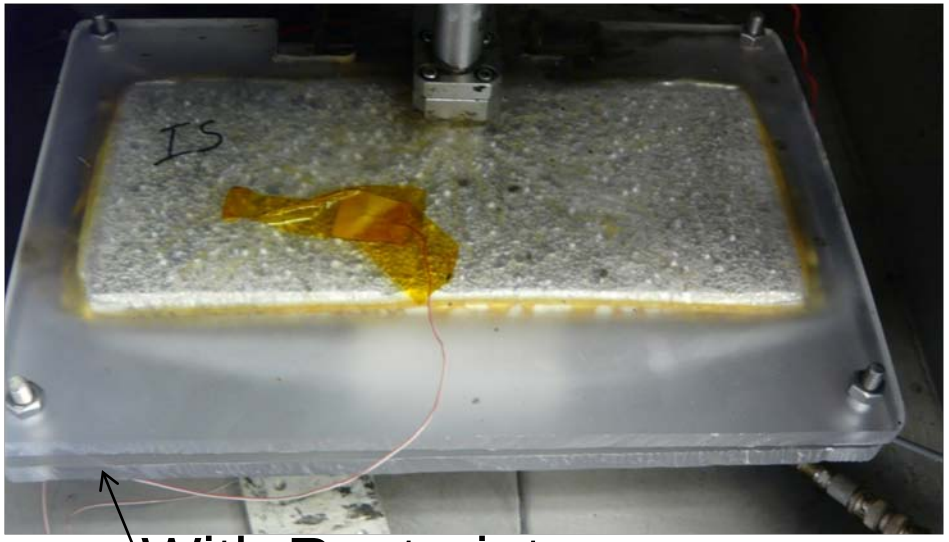
SKC 15 Ah External Short Test



Cell ID	Pre OCV (V)	OCV at Peak Current (V)	Post OCV (V)	Load Value (mΩ)	Peak Current (A)
204	4.165	≈2.03	1.353	3.60	482.00
301	4.148	≈2.49	4.083	1.76	1,410.10
302	4.151	≈2.37	1.733	1.76	1,393.30
309	4.137	≈2.77	0.658	1.60	1,395.80
313	4.161	≈2.96	2.853	1.60	1,404.10

Cell Swelling

SKC 15 Ah Li-ion -Simulated Internal Short Test



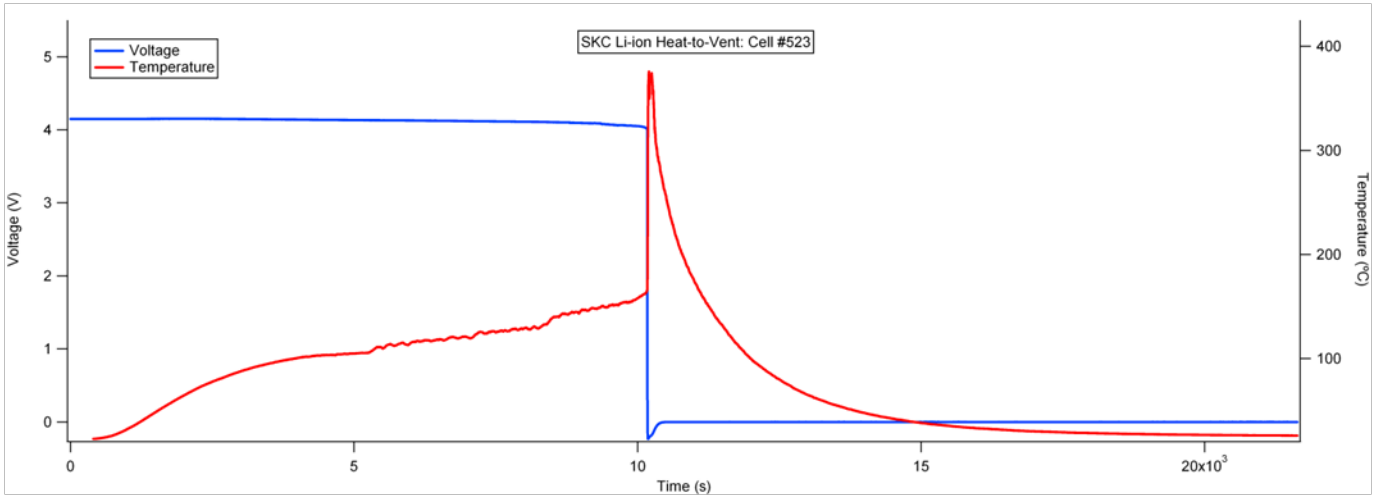
With Restraints

Without Restraints

Thermal runaway

SKC 15 Ah Li-ion - Heat to Vent Test

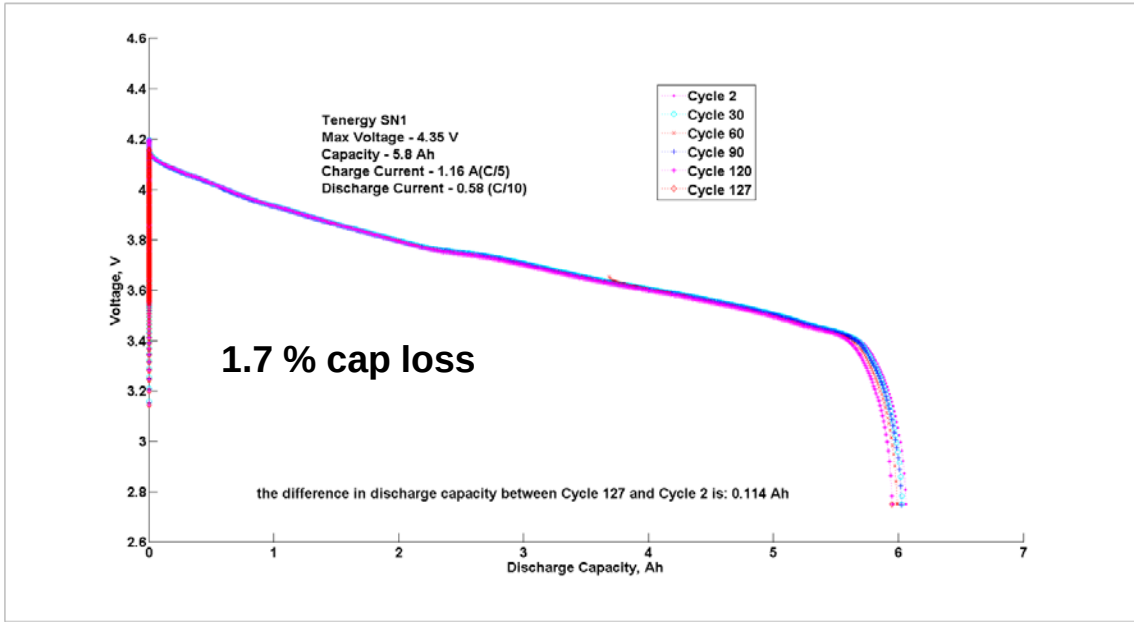
Venting and
thermal runaway above
175 deg C

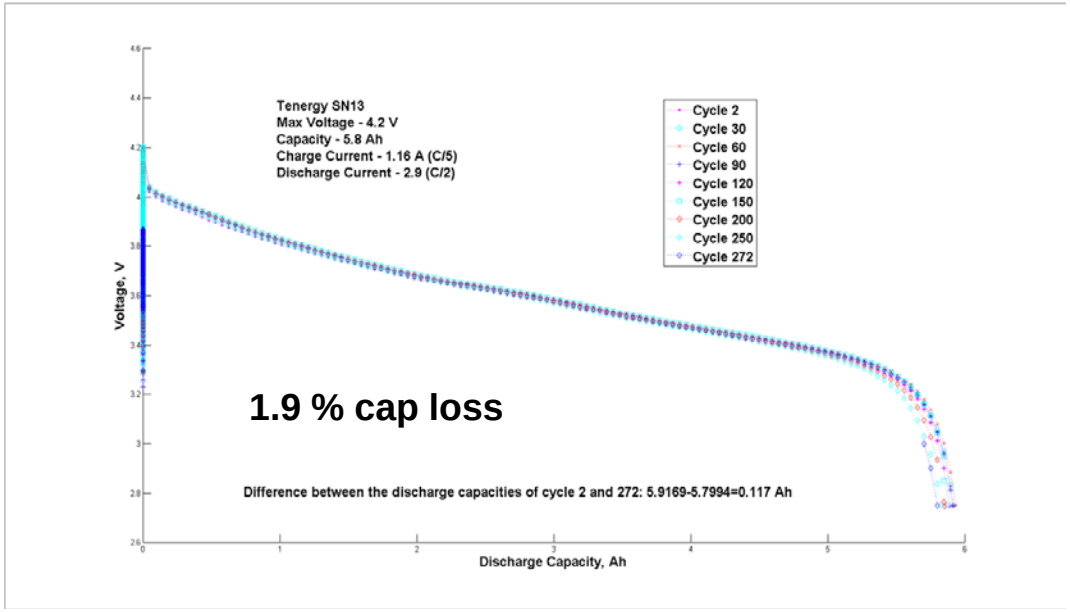


SKC 15 Ah Li-ion Cell Test Results Summary

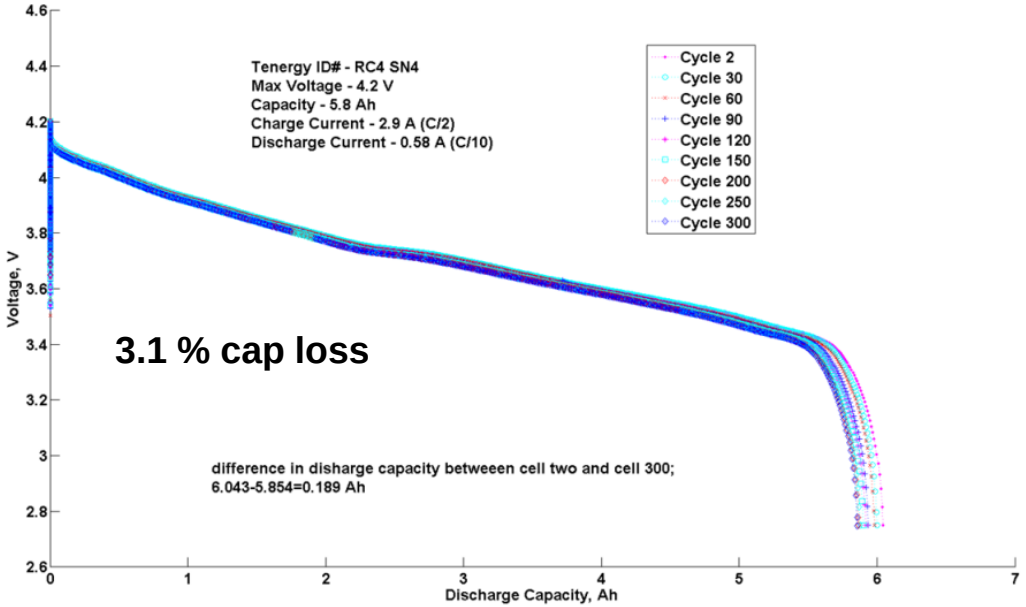
- The cells provide significant performance at the rates studied
  - less than 3% capacity loss after 500 cycles at 1 C rates
- The cells did not show any change in performance while being charged and discharged under vacuum conditions when they were restrained and displayed a loss in capacity if the cells were not restrained.
- The cells swell under overcharge and external short conditions but go into thermal runaway during simulated internal short and heat-to-vent test conditions.

Rate Capability Tests for Tenergy 6 Ah Li-ion Cell



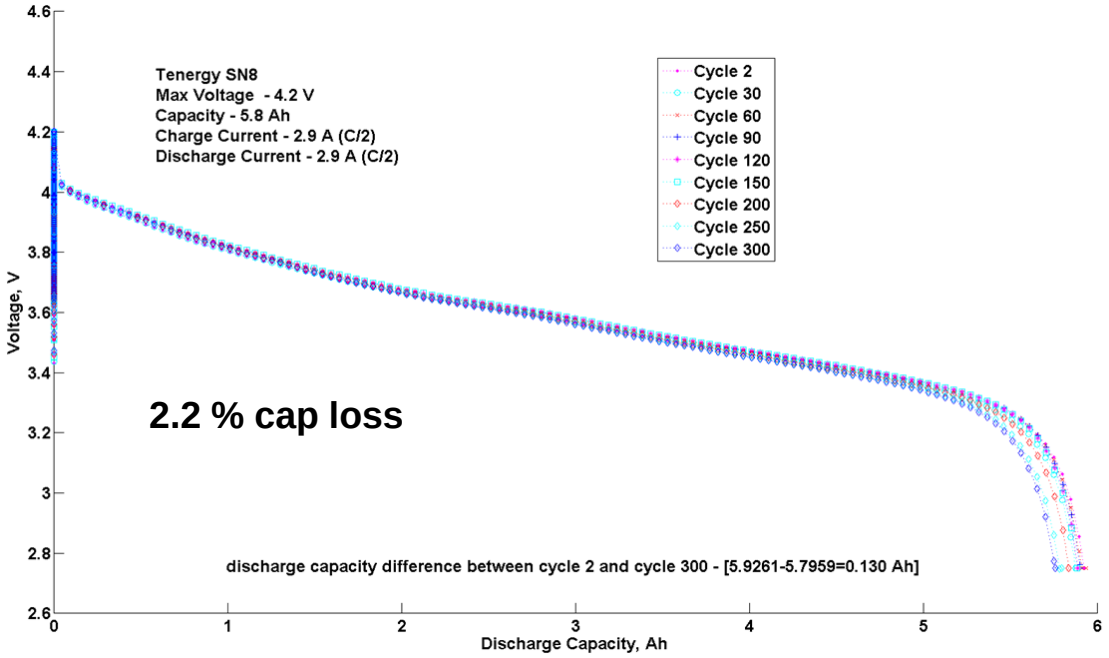


Rate Capability Tests for Tenergy 6.0 Ah Li-ion Cells



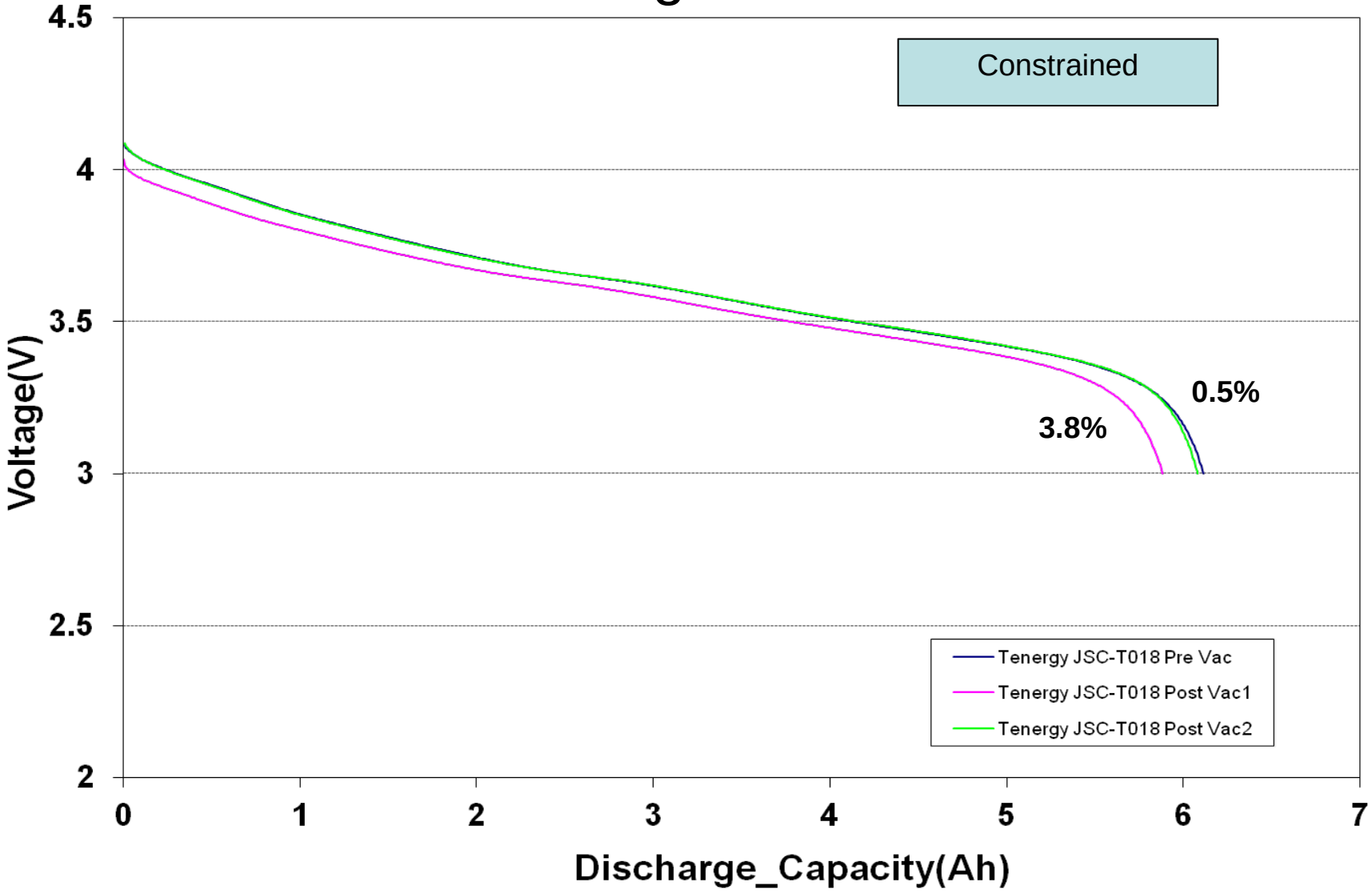
3.1 % cap loss

2% less initial cap between C/10 and C/2

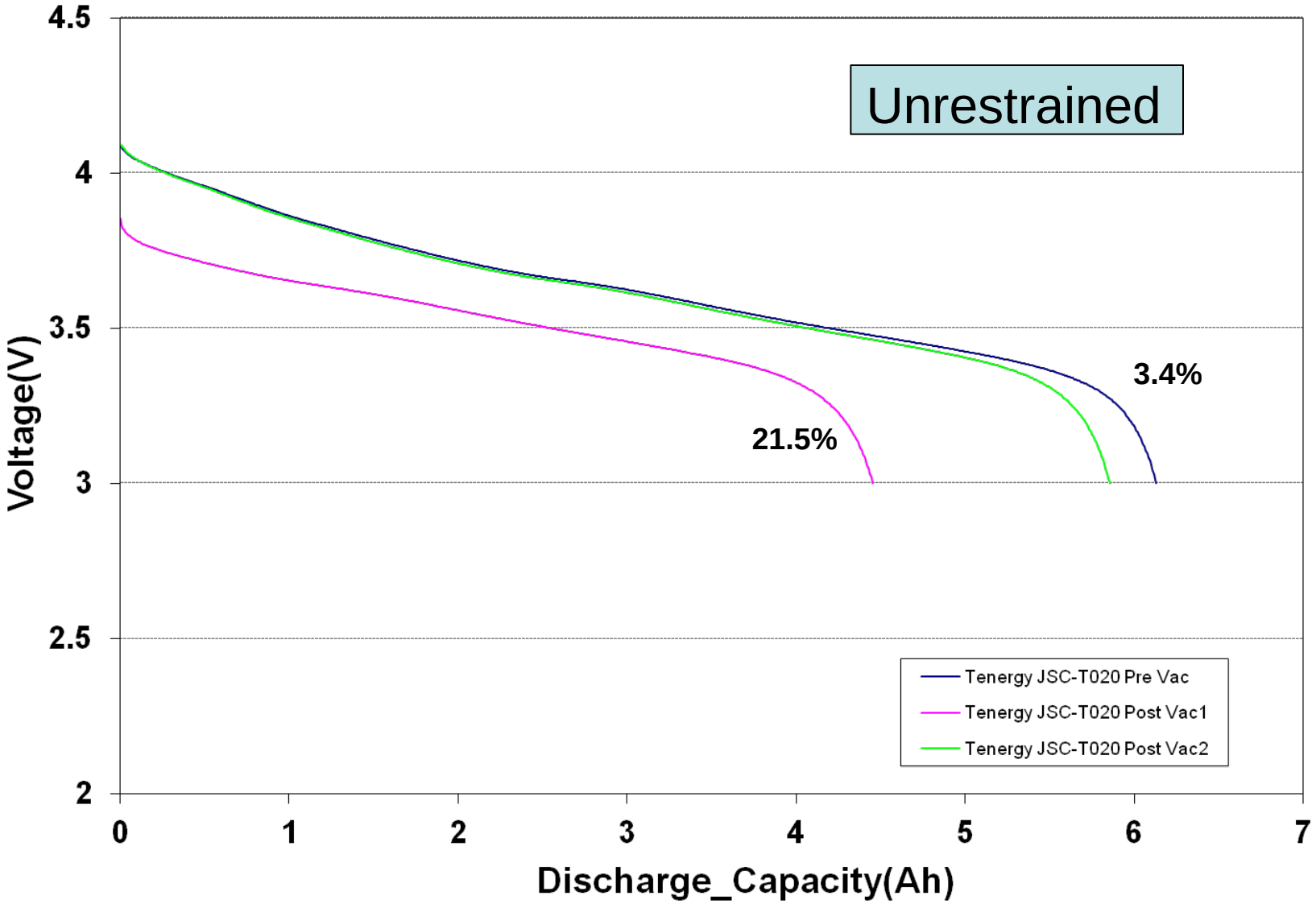


2.2 % cap loss

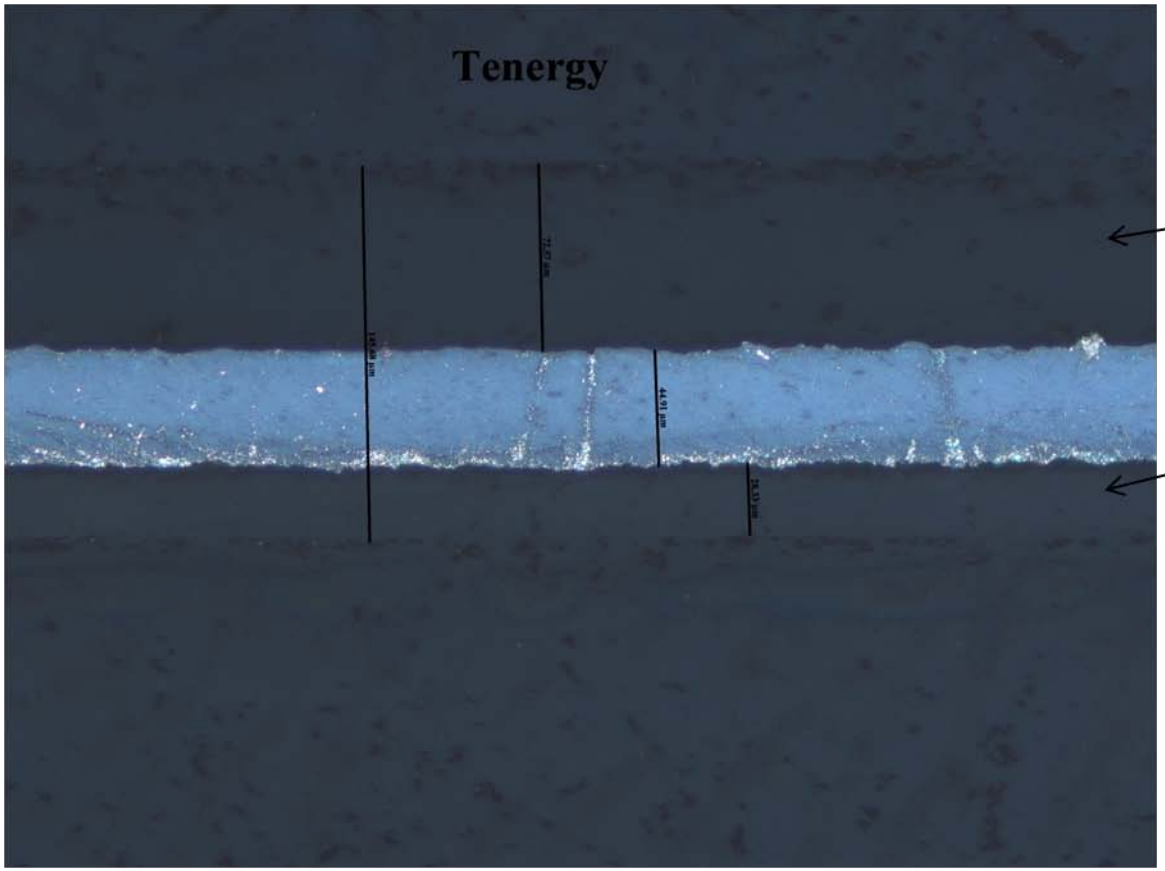
Tenergy Li-ion Cell Performance After Vacuum Cycling and Storage at Ambient



Tenergy Li-ion Cell Performance After Vacuum Cycling and Storage at Ambient



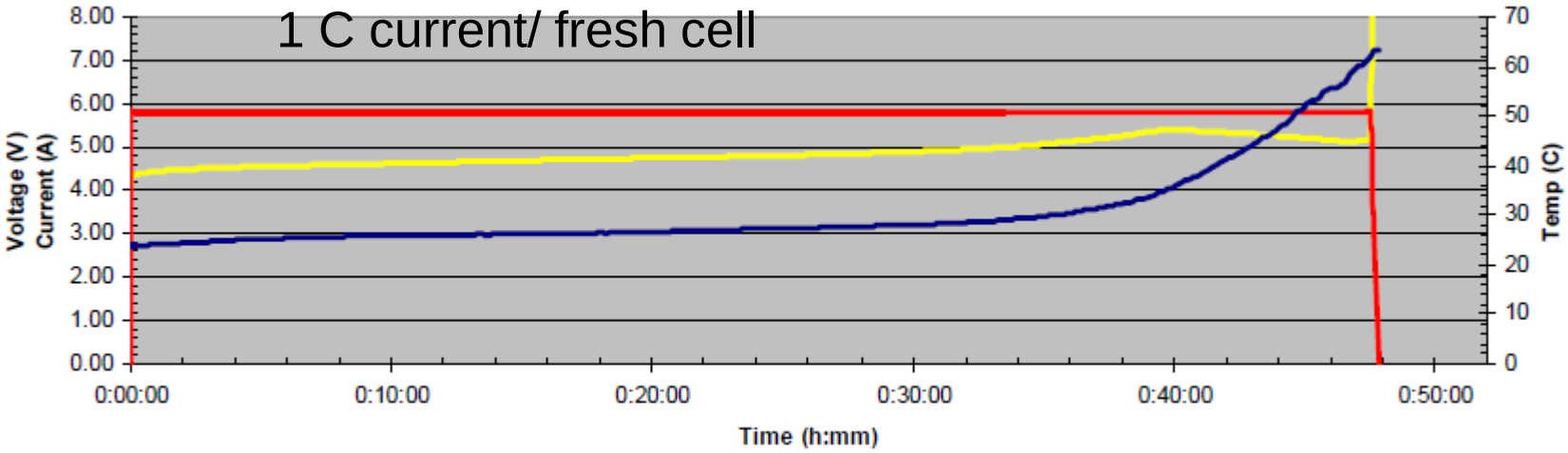
Pouch Material Cross-Section



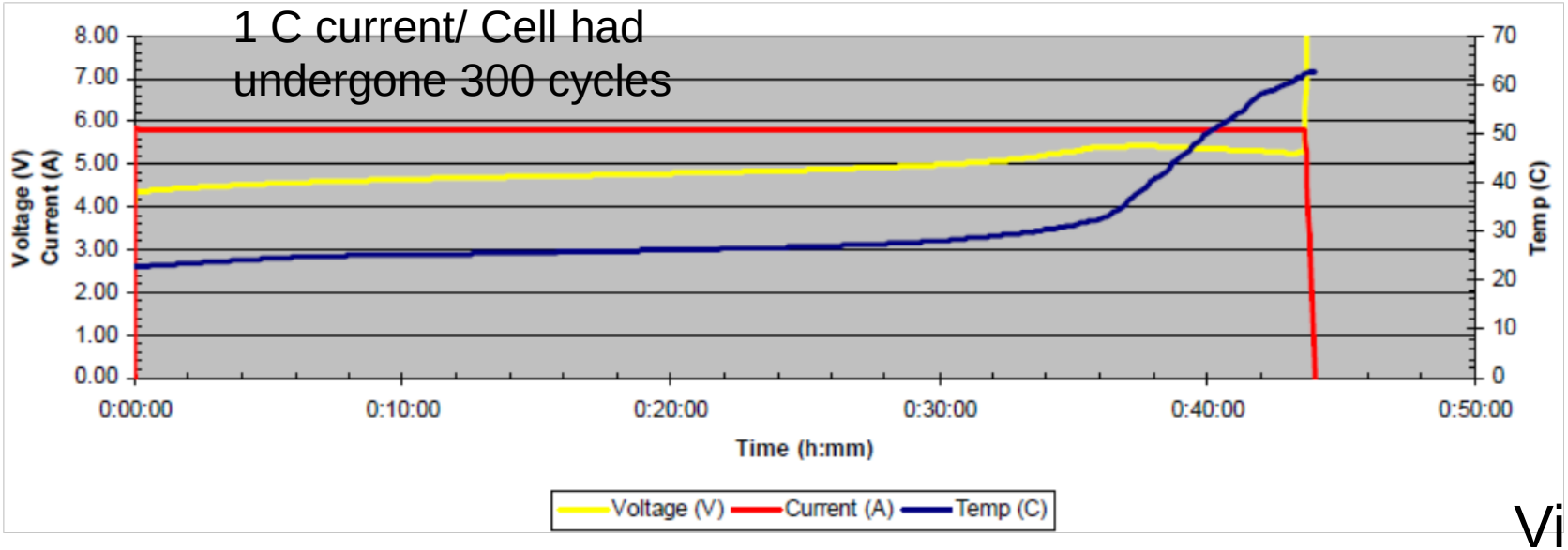
Outside:
Nylon 6

Inside:
Polypropylene

Tenergy 6.0 Ah Li-ion Prismatic Pouch Cell Overcharge Test



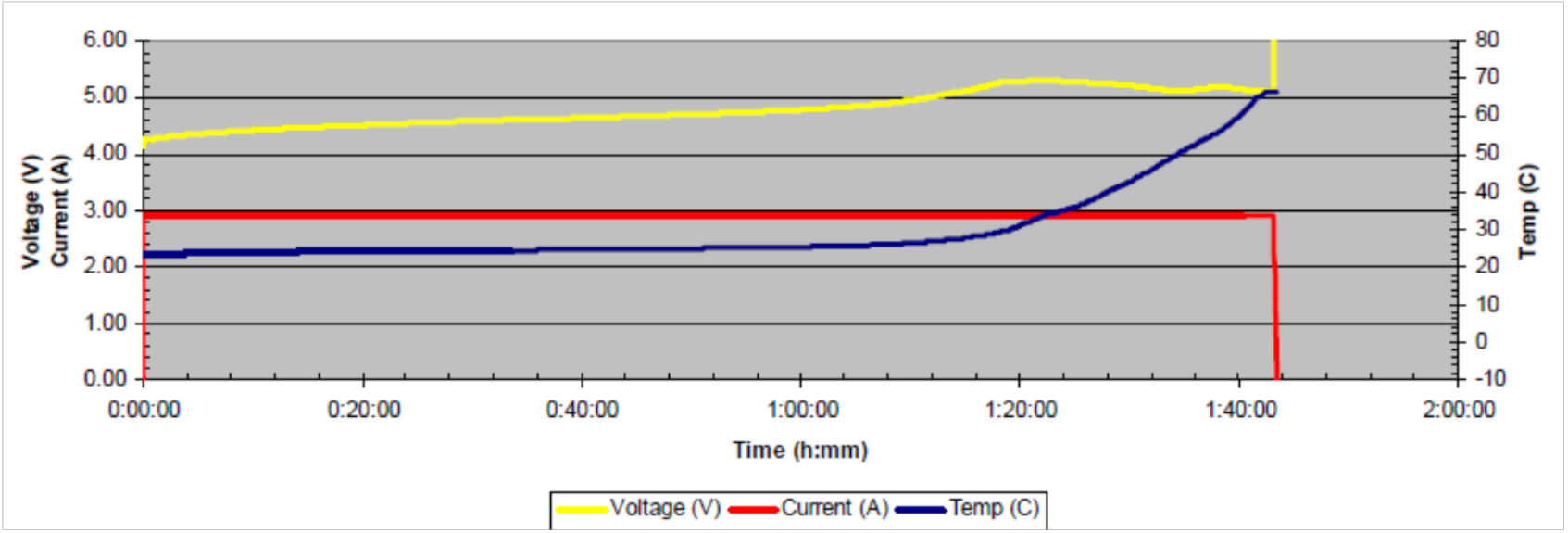
Both cells vented violently



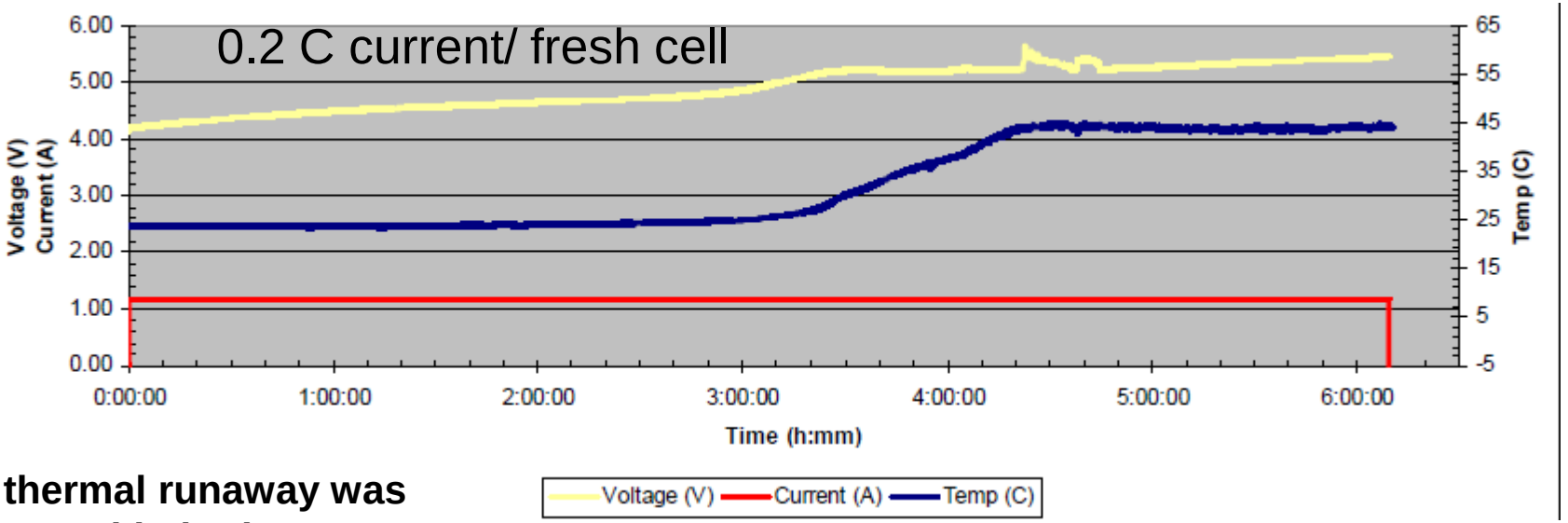
Video

Overcharge Test on Tenergy 6.0 Ah Li-ion Prismatic Pouch Cell

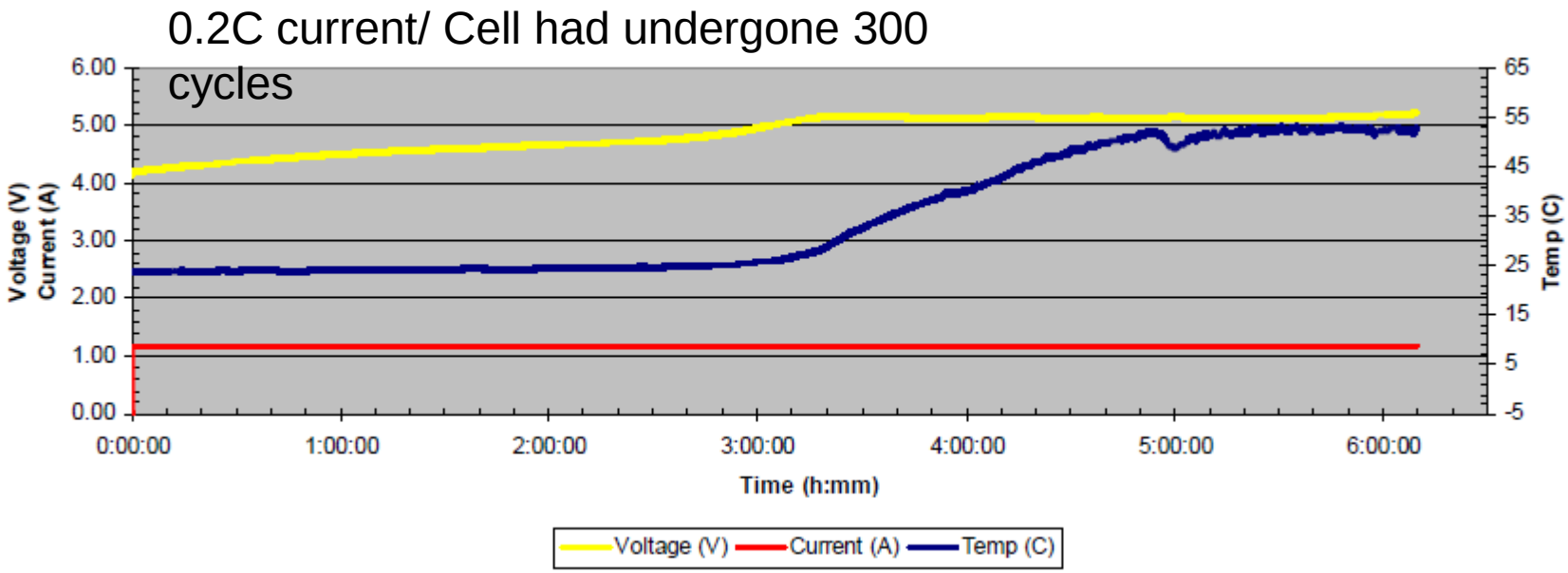
0.5 C current/ fresh cell



Overcharge Test of Tenergy 6.0 Ah Li-ion Cell



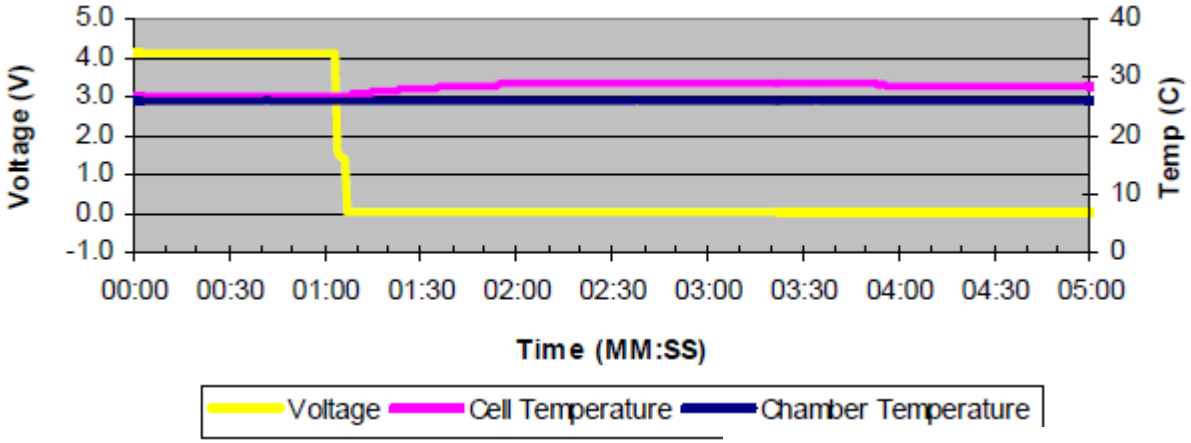
No thermal runaway was Observed in both cases

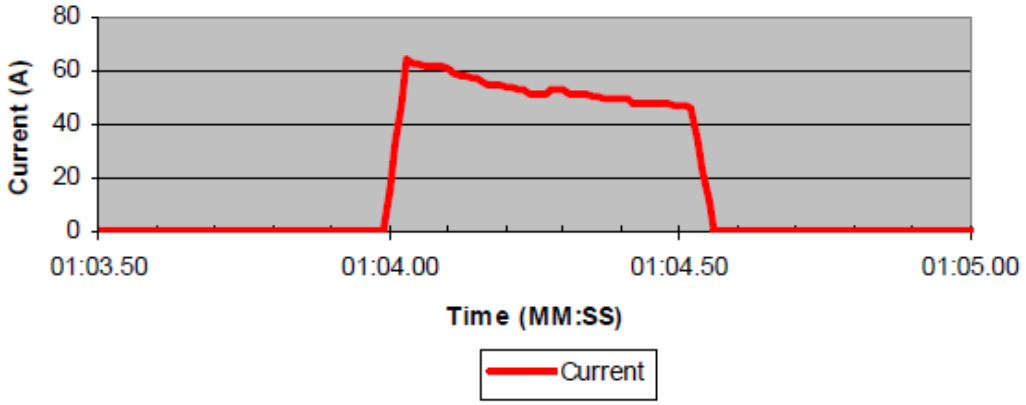


External Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Resistance (mOhm)	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Maximum Current (A)	Notes
20	Fresh Chg	1	11	30	4.1284	20.4	28.9	62.0	Cathode tab burned off
20	Fresh Chg	2	8	30	4.1327	20.4	27.2	63.0	Cathode tab burned off
20	Fresh Chg	3	9	30	4.1325	20.3	29.7	65.0	Cathode tab burned off
20	Fresh Chg	3-Cell	25,26,27	27	12.431	63.2	27.2	113.0	Cathode tab burned off

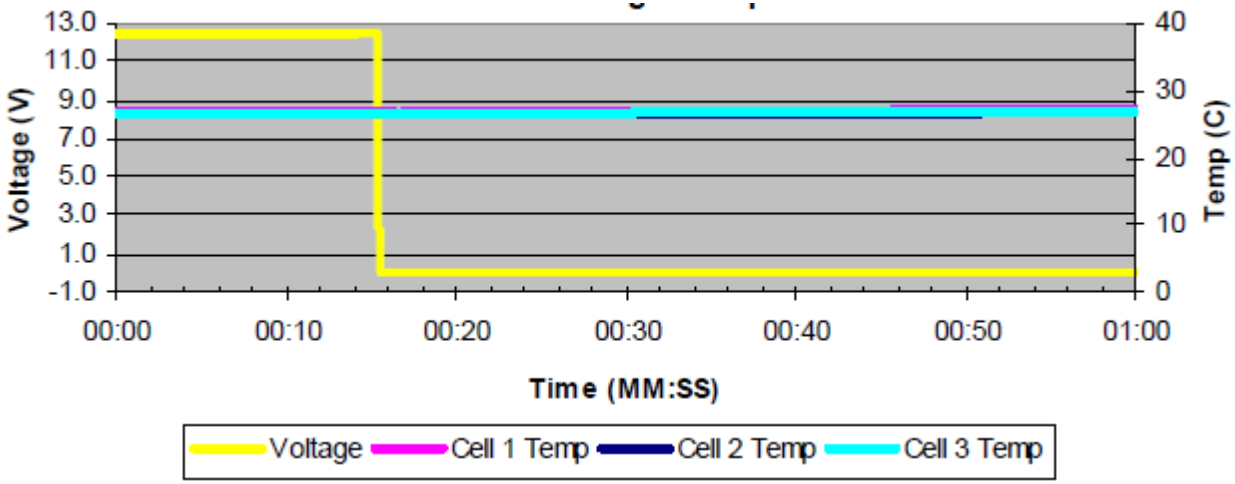
Table 2.2.1: Test Summary Table

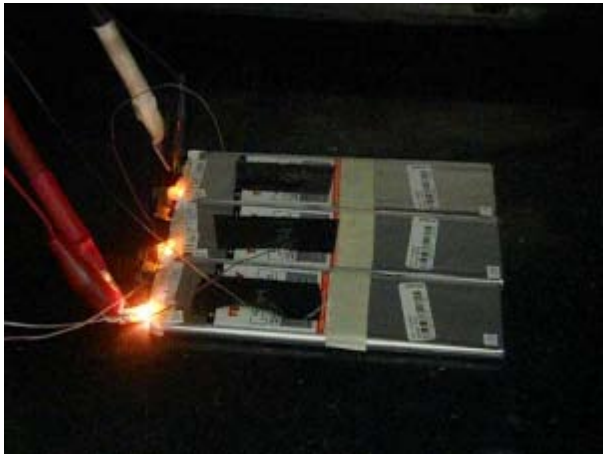


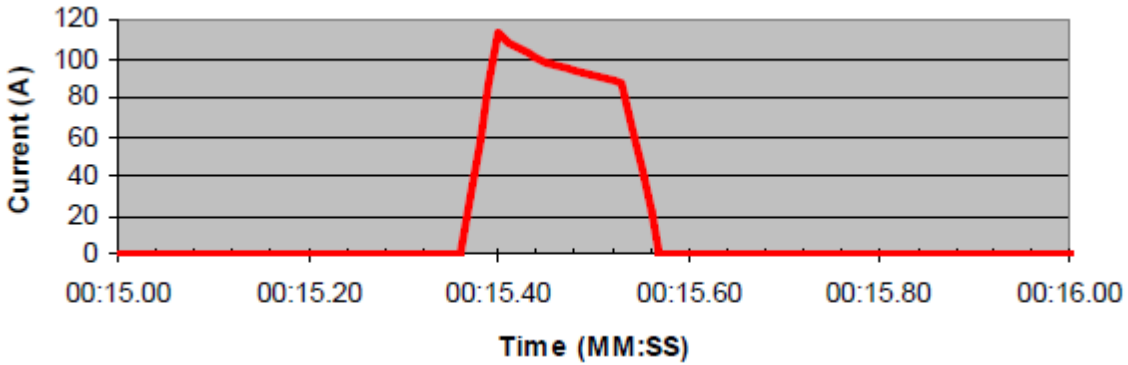


External Short Test on 3S String of Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

113 A max; 27 deg C max





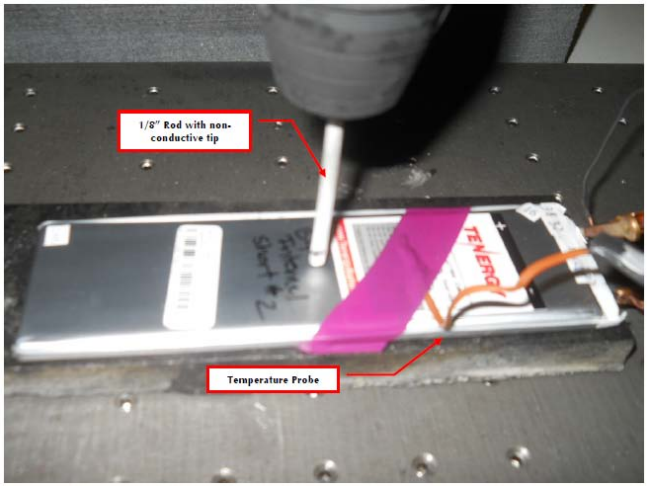


Cathode Tabs from all three cells burned off and became disconnected

Simulated Internal Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Notes
20	Fresh Chg	1	18	4.140	20.5	172.6	Fire
20	Fresh Chg	2	20	4.137	20.6	309.8	Fire

Table 2.4.1: Test Summary Table



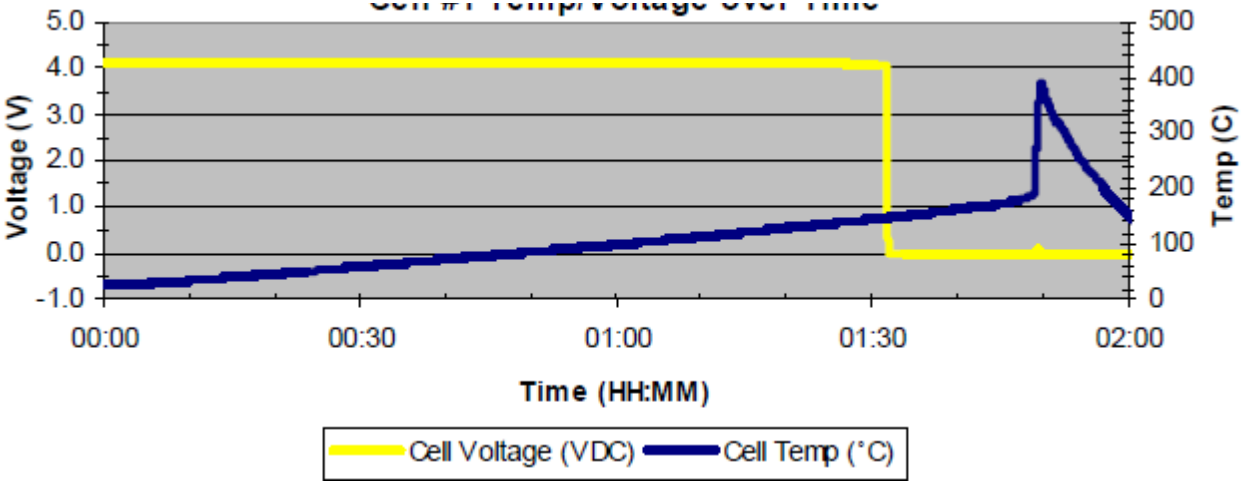
Burst Pressure Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Max Pressure (kPa)
20	Fresh Chg	1	40	662
20	Fresh Chg	2	5	617

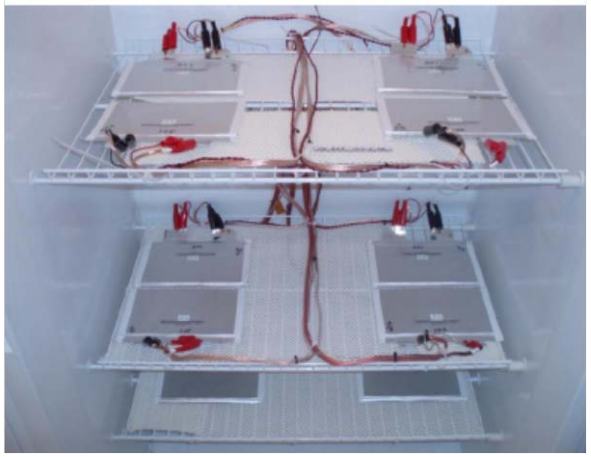
89/96 psi

Heat-to-Vent Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

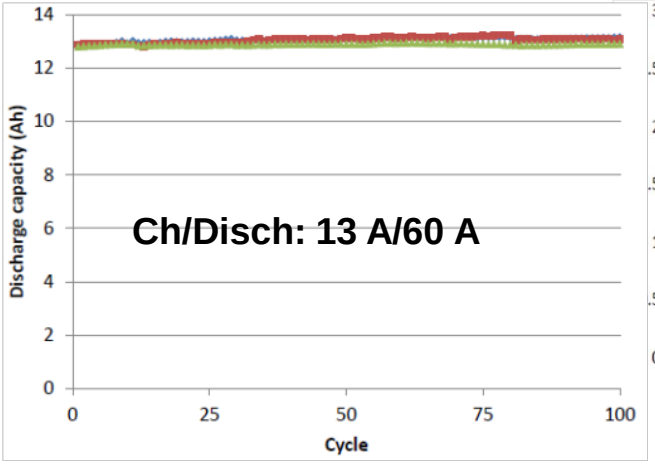
Test Temp ('C)	Sample Condition	Sample #	Sample ID	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Notes
20	Fresh	1	15	4.1438	20.3	189.8	Fire
20	Fresh	2	14	4.1397	20.5	192.0	Fire

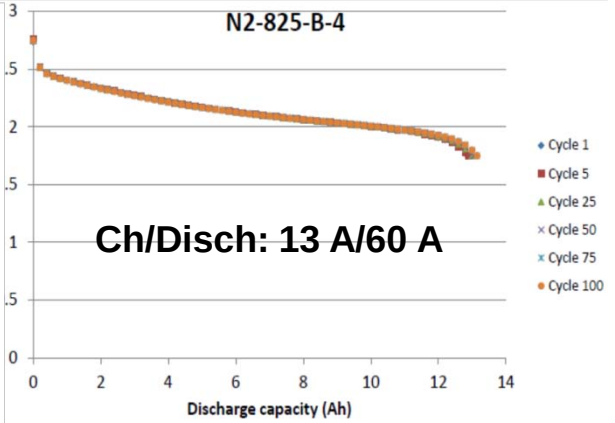


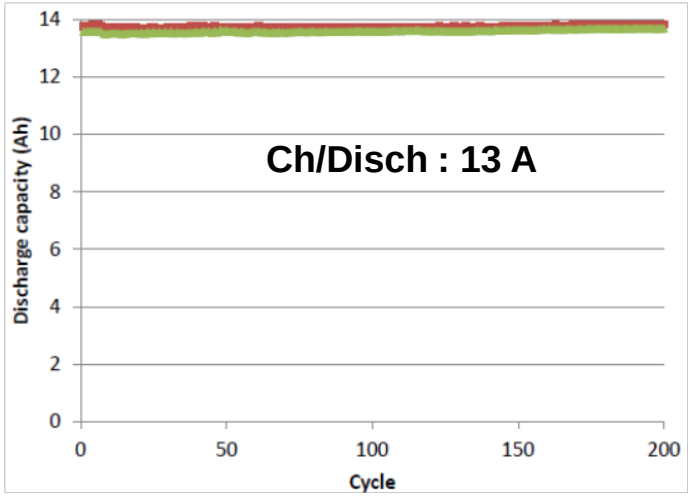
Altairnano 13 Ah Li-ion Cell Tests

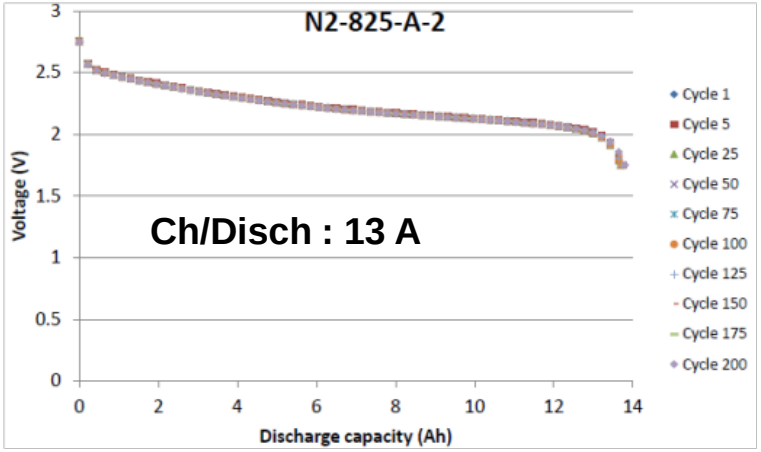


Nameplate Capacity: 13 Ah
Average Capacity at C/2: 14.3 Ah





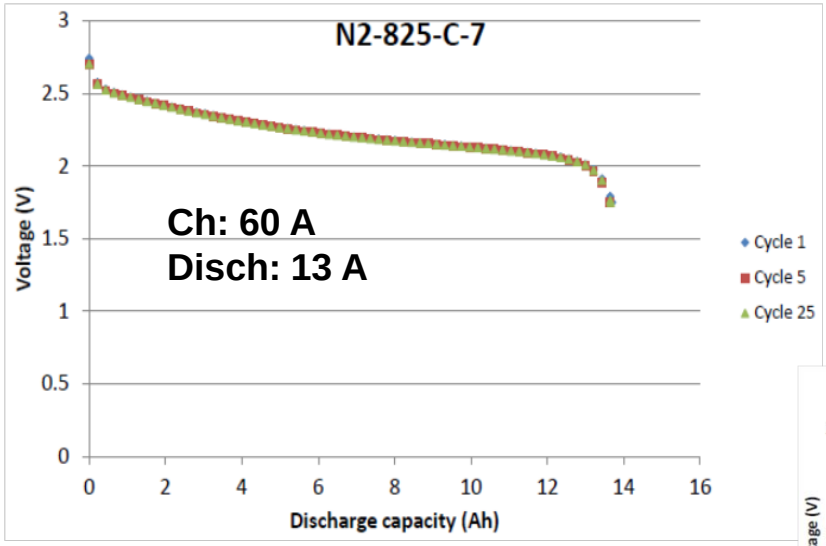


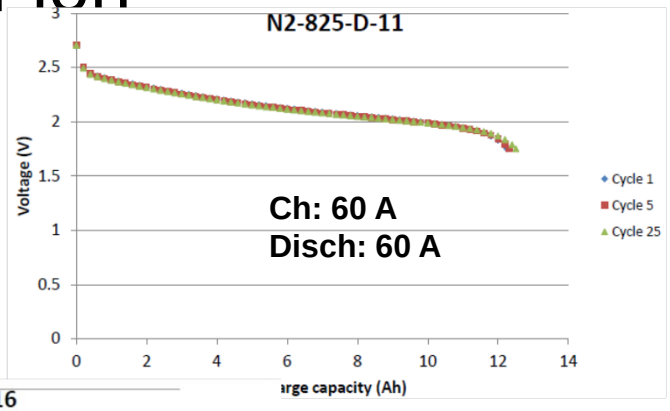


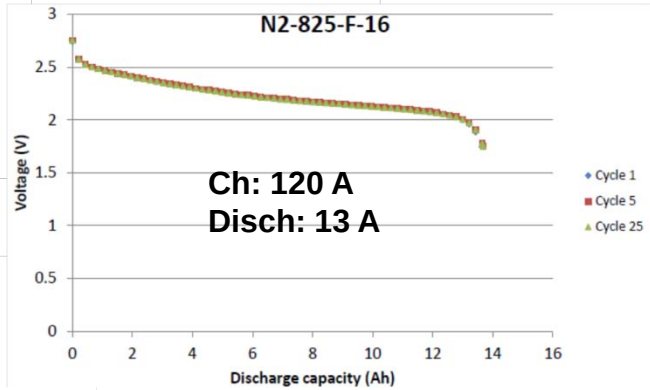
Tenergy Li-ion Cell Test Summary

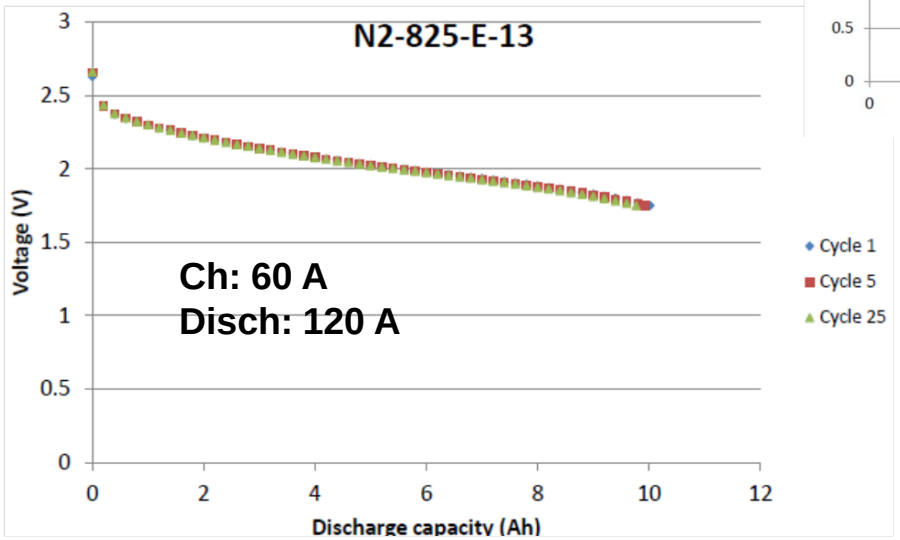
- The Tenergy Li-ion Pouch cells performed well under different rate protocols with a maximum of 3 % capacity loss for the 300 cycles studied.
- The cells lose capacity when tested under vacuum conditions in an unrestrained mode.
- The cells go into thermal runaway when overcharged at 1 C and 0.5 C rates but show tolerance to overcharge at 0.2C rates.

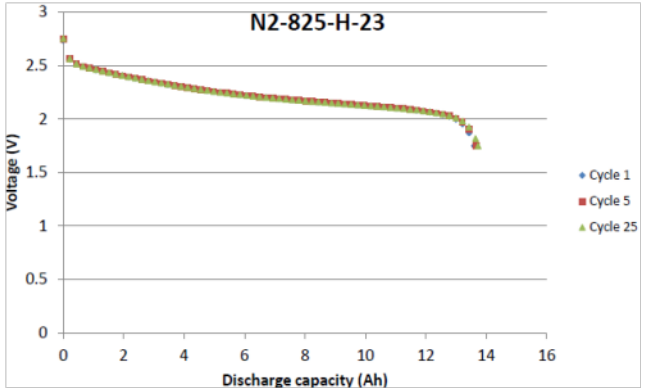
Altairnano 13 Ah Li-ion-





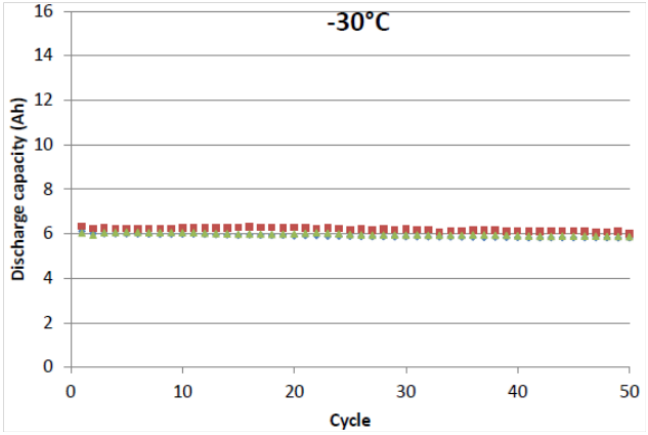


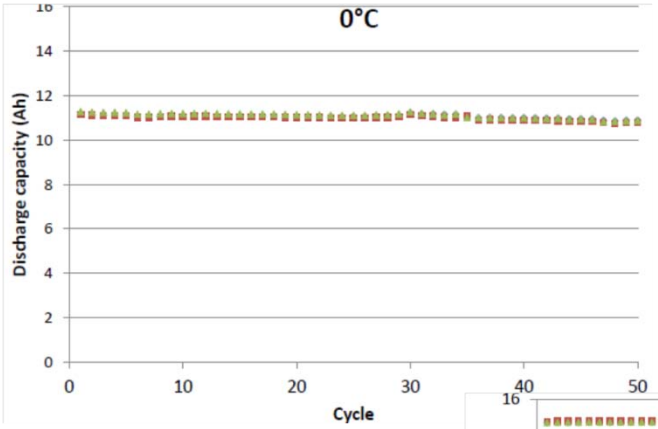


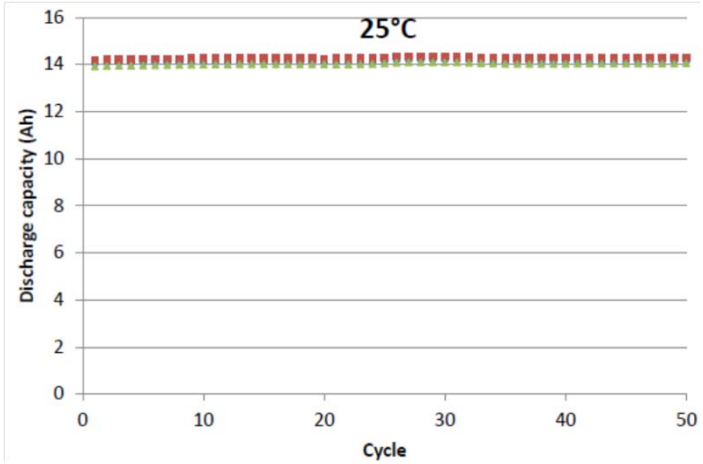


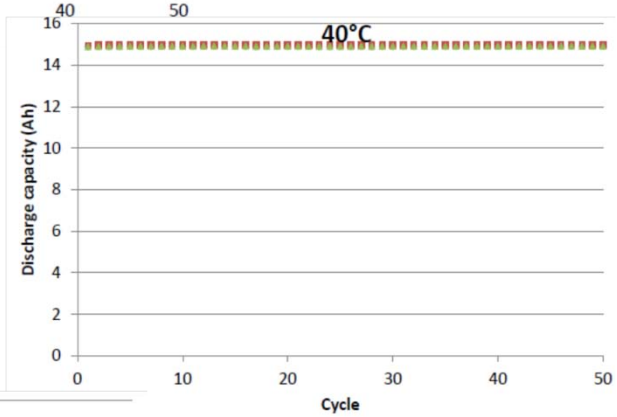
Altairnano 13 Ah Li-ion Tests

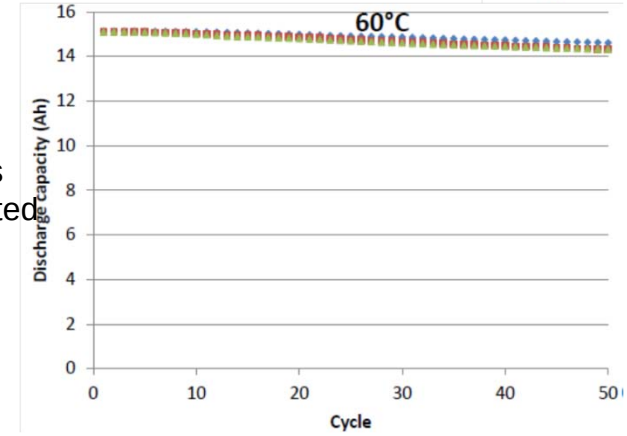
C: 6.5 A
D: 13 A





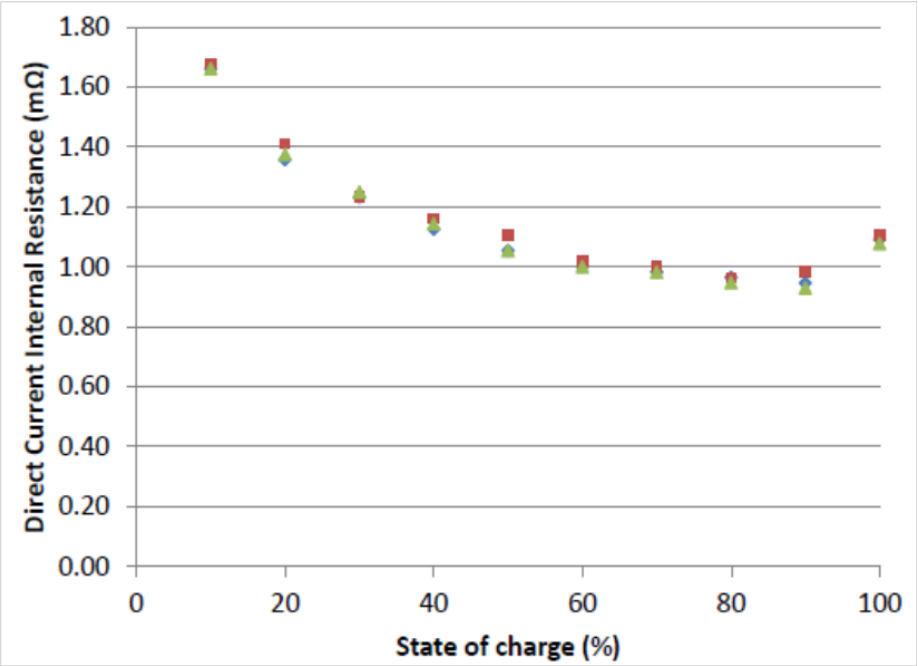






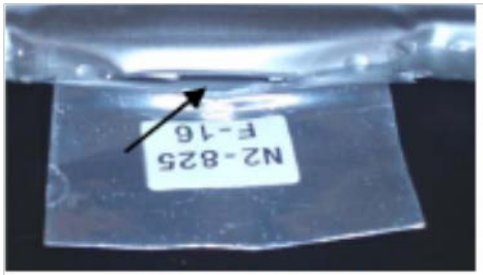
Lower capacity is obtained at lower temperatures but does not show degradation for the cycles tested

Altairnano 13 Ah Li-ion Cell Internal Resistance



Burst Pressure Test

MPS ID	Burst pressure (psi)	Burst location
N2-825-E-15	25	side seal
N2-825-F-16	31	seal over tab
N2-825-F-18	23	seal over and near tab



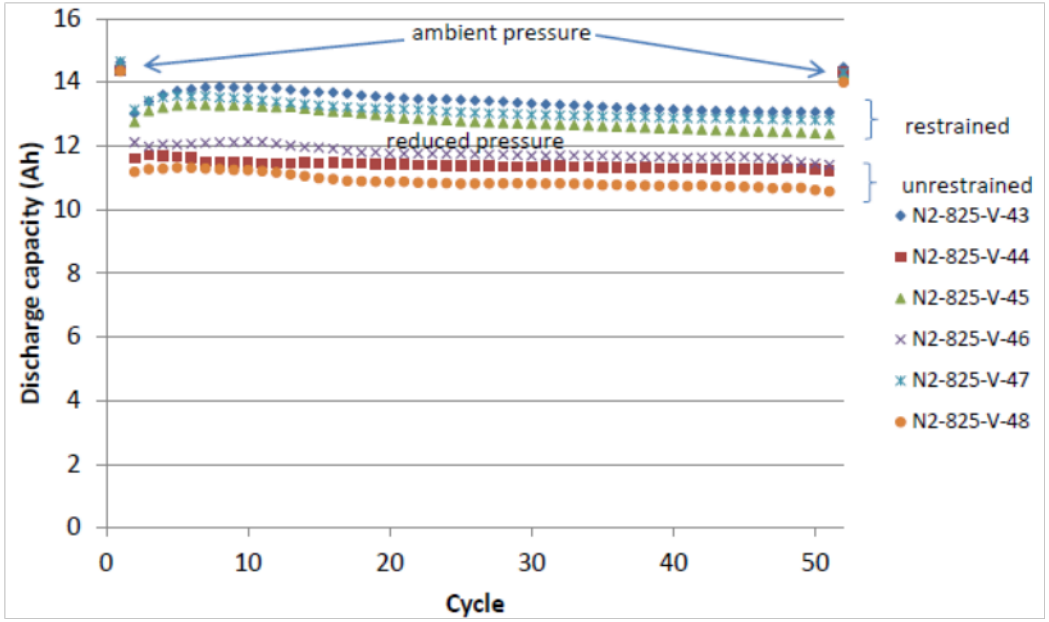
N2-825-F-16

Altairnano 13 Ah Cycling in Vacuum Conditions

MPS ID	In fixture?	Pre-test weight (g)	Post-test weight (g)	Δ weight (g)	Reduced pressure (psi)	Post-test inspection
N2-825-V-43	Y	401.81	401.79	0.02	0.050 ± 0.016	OK
N2-825-V-44	N	400.28	400.27	0.01		deformed
N2-825-V-45	Y	401.17	401.16	0.01	0.050 ± 0.022	OK
N2-825-V-46	N	400.80	400.78	0.02		deformed
N2-825-V-47	Y	401.16	401.14	0.02	0.046 ± 0.013	OK
N2-825-V-48	N	401.31	401.28	0.03		deformed

Higher capacities observed with restrained than with unrestrained cells

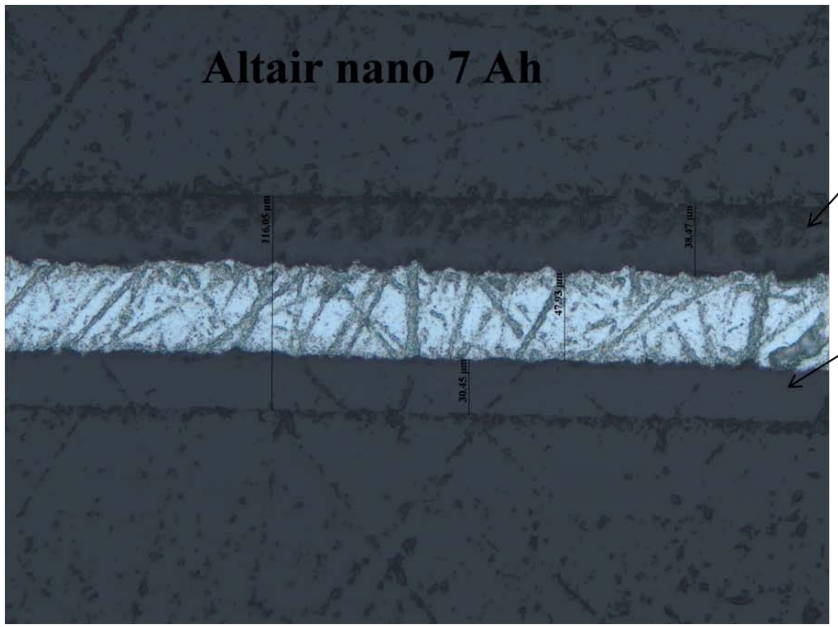
	Initial cycle		Final cycle		
MPS ID	Discharge capacity (Ah)	Temp. (°C)	Discharge capacity (Ah)	Temp. (°C)	Δ Discharge capacity (Ah)
N2-825-V-43	14.618	22.5 ± 0.4	14.469	22.4 ± 0.4	0.149
N2-825-V-44	14.377		14.323		0.054
N2-825-V-45	14.389	22.5 ± 0.3	14.230	22.3 ± 0.4	0.159
N2-825-V-46	14.352		14.338		0.014
N2-825-V-47	14.656	23.4 ± 0.8	14.298	21.2 ± 0.4	0.358
N2-825-V-48	14.345		13.998		0.347



Inflated cell

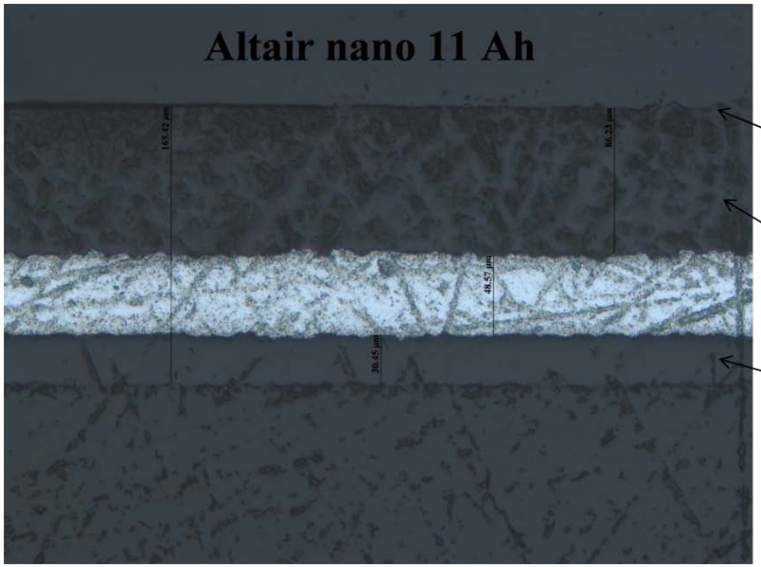
Deflated cell

Pouch Material Cross-Section



Outside:
Nylon 6

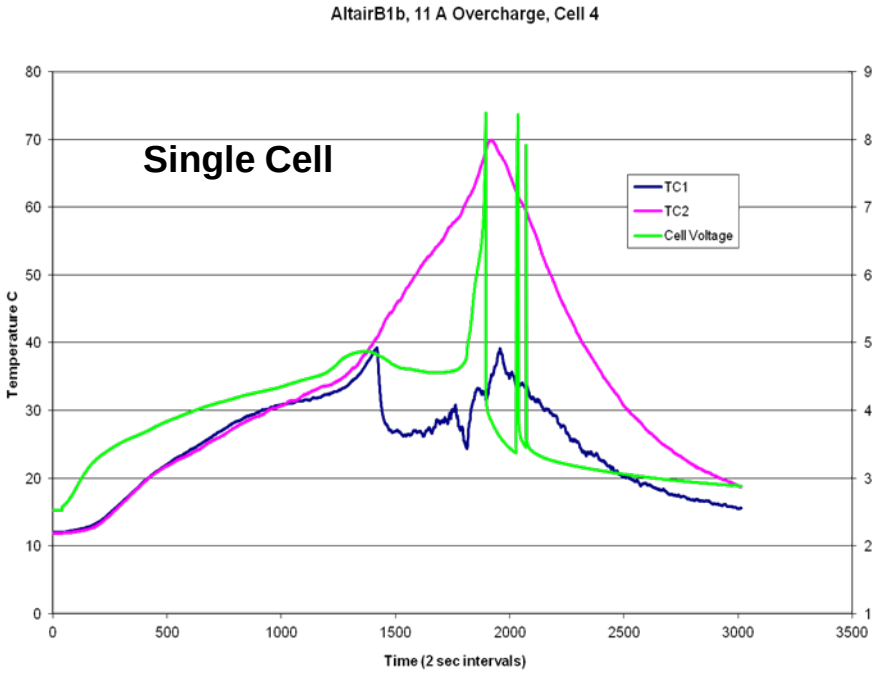
Inside:
Polypropylene

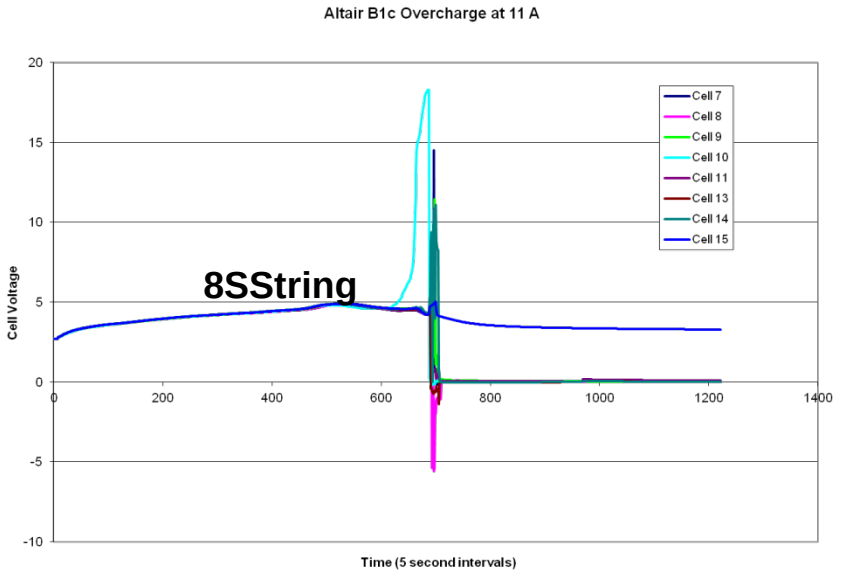


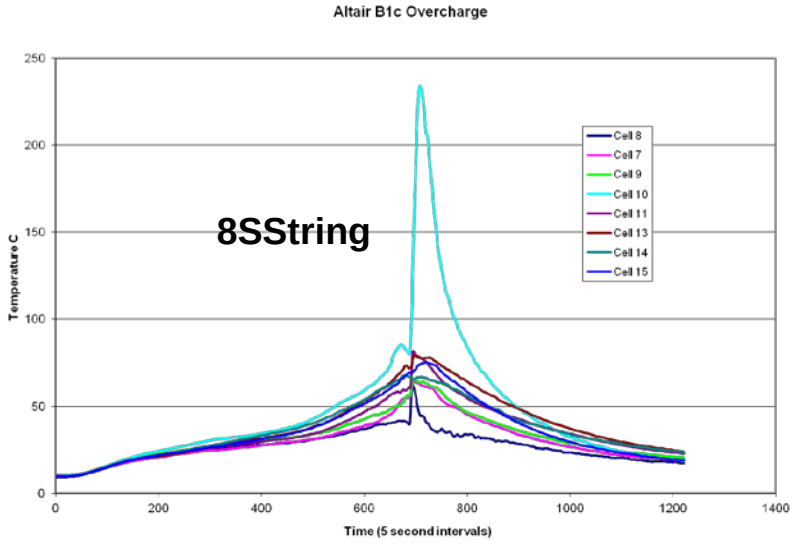
Outside:
Polyethylene terephthalate &
Nylon 6

Inside:
Polypropylene

Altairnano Safety Tests



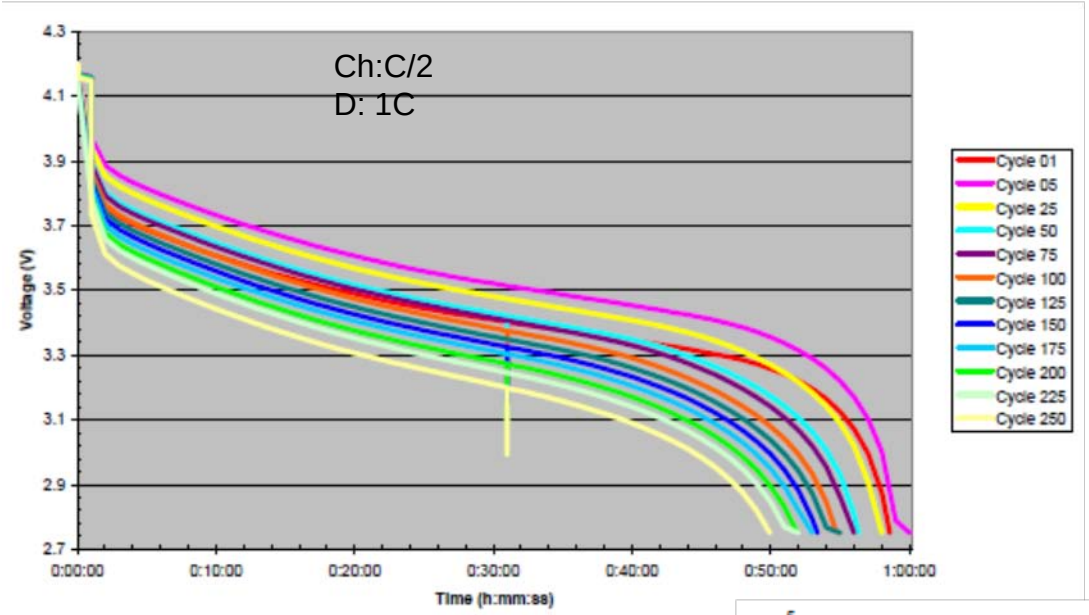




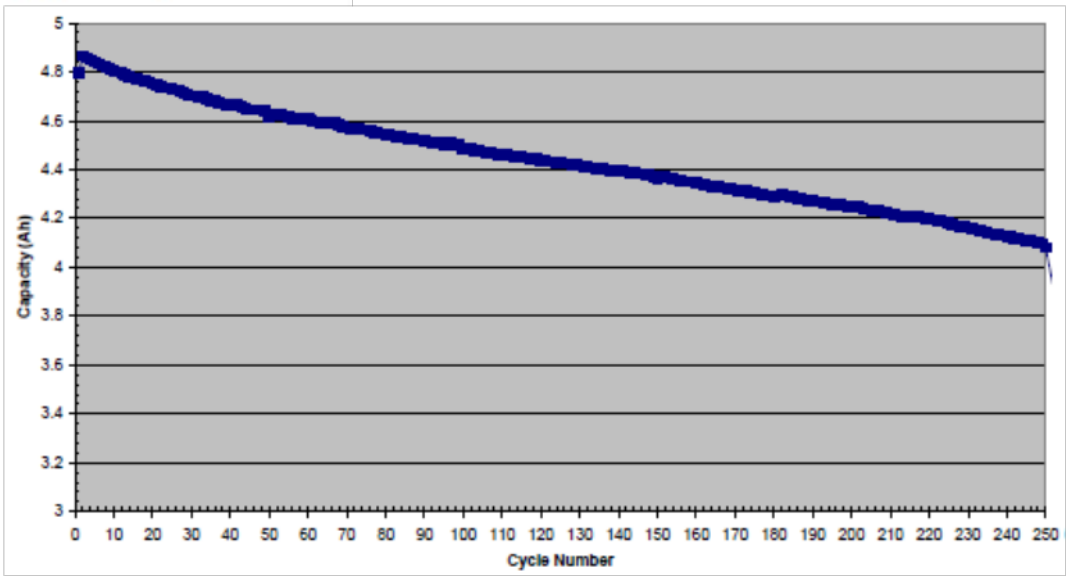
Altairnano Li-ion Cell Test Summary

- The Altairnano Li-ion cells performed well at the different rate protocols and did not display any change in capacity for all the discharge rates from 1C to 10C and for the number of cycles studied .
- The cells provide less than half the room temperature capacity at -30 deg C but the capacity does not show any degradation for the 50 cycles studied.
- The cells showed good performance under vacuum conditions and show a slight drop in capacity under vacuum conditions compared to that at ambient.
- Although the cells showed good tolerance to abuse as single cells, a string of 8 cells goes into thermal runaway during an overcharge test.

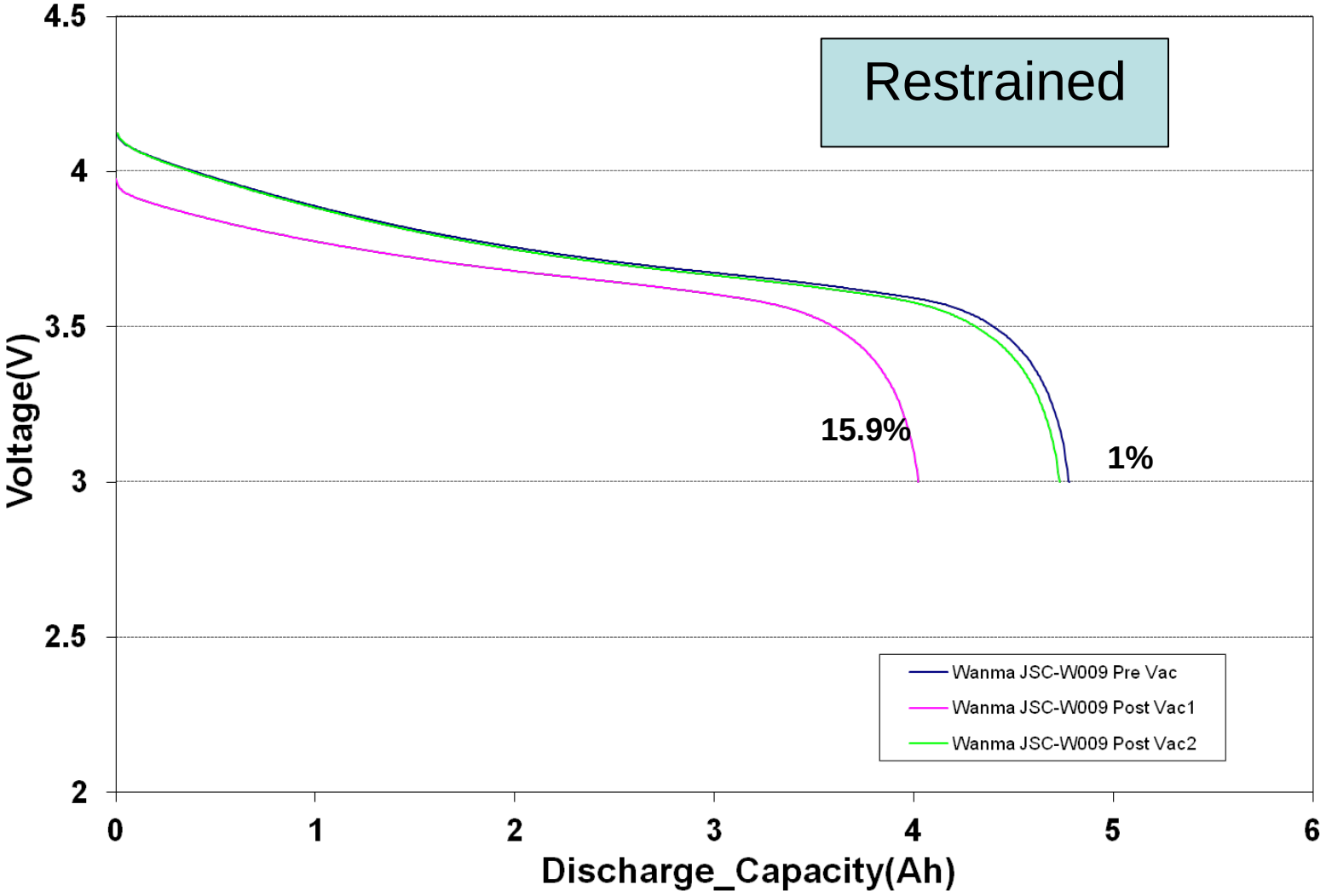
Wanma Performance Tests



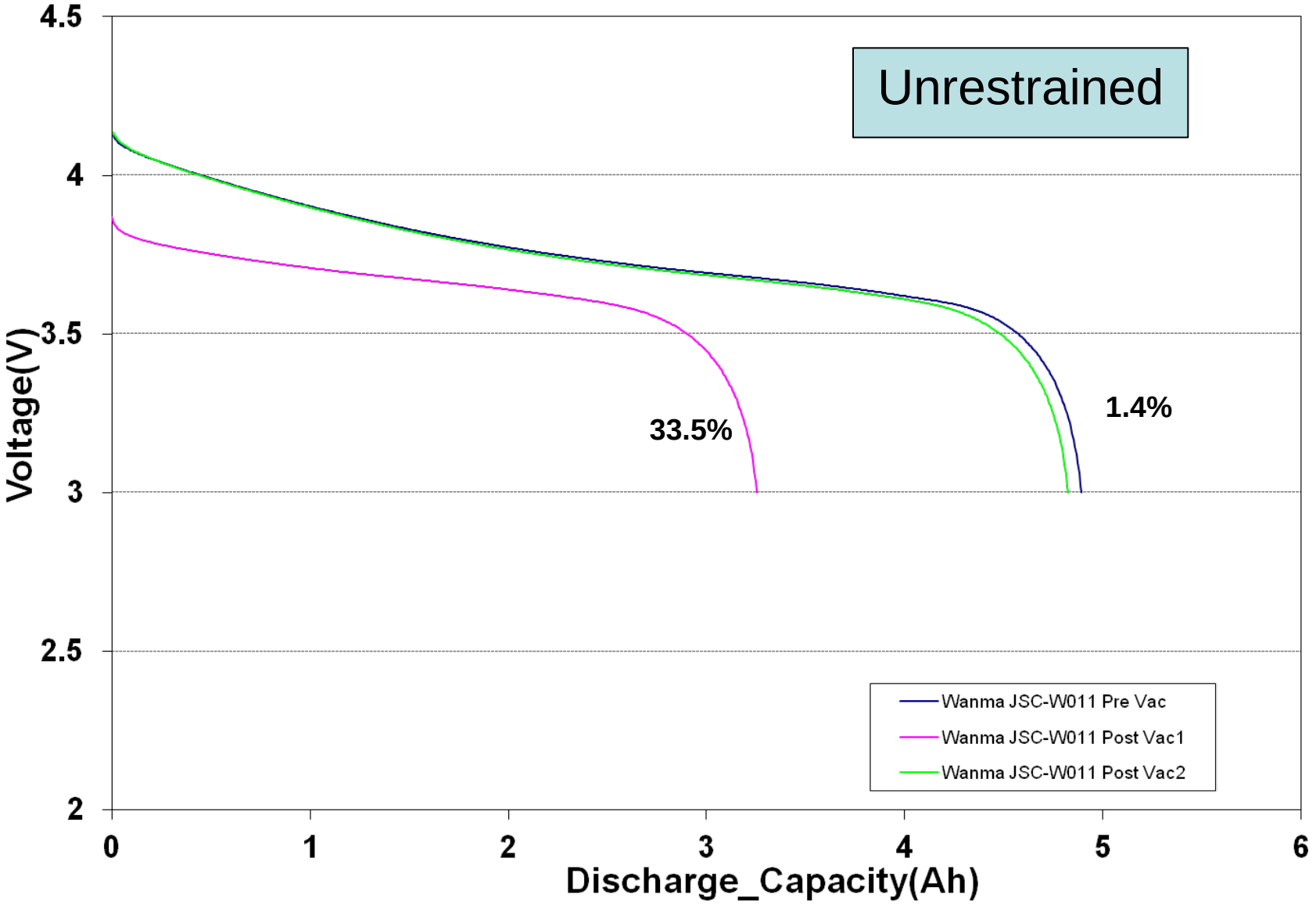
4.8 Ah Cycle 1
4.1 Ah Cycle 250



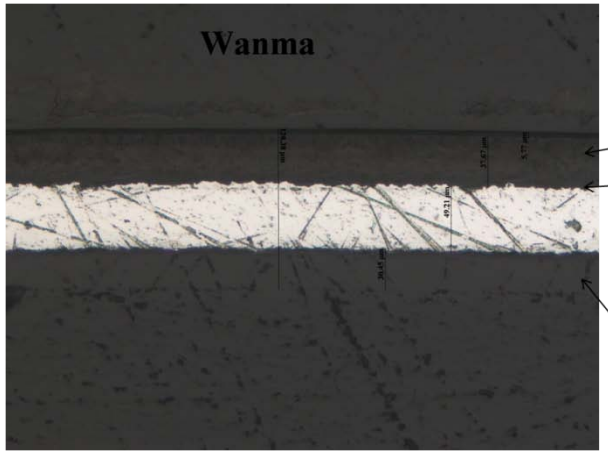
Wanma Li-ion Pouch Cell Vacuum Exposure With Storage under Ambient



Wanma Li-ion Pouch Cell Vacuum Exposure With Storage under Ambient



Pouch Material Cross-Section

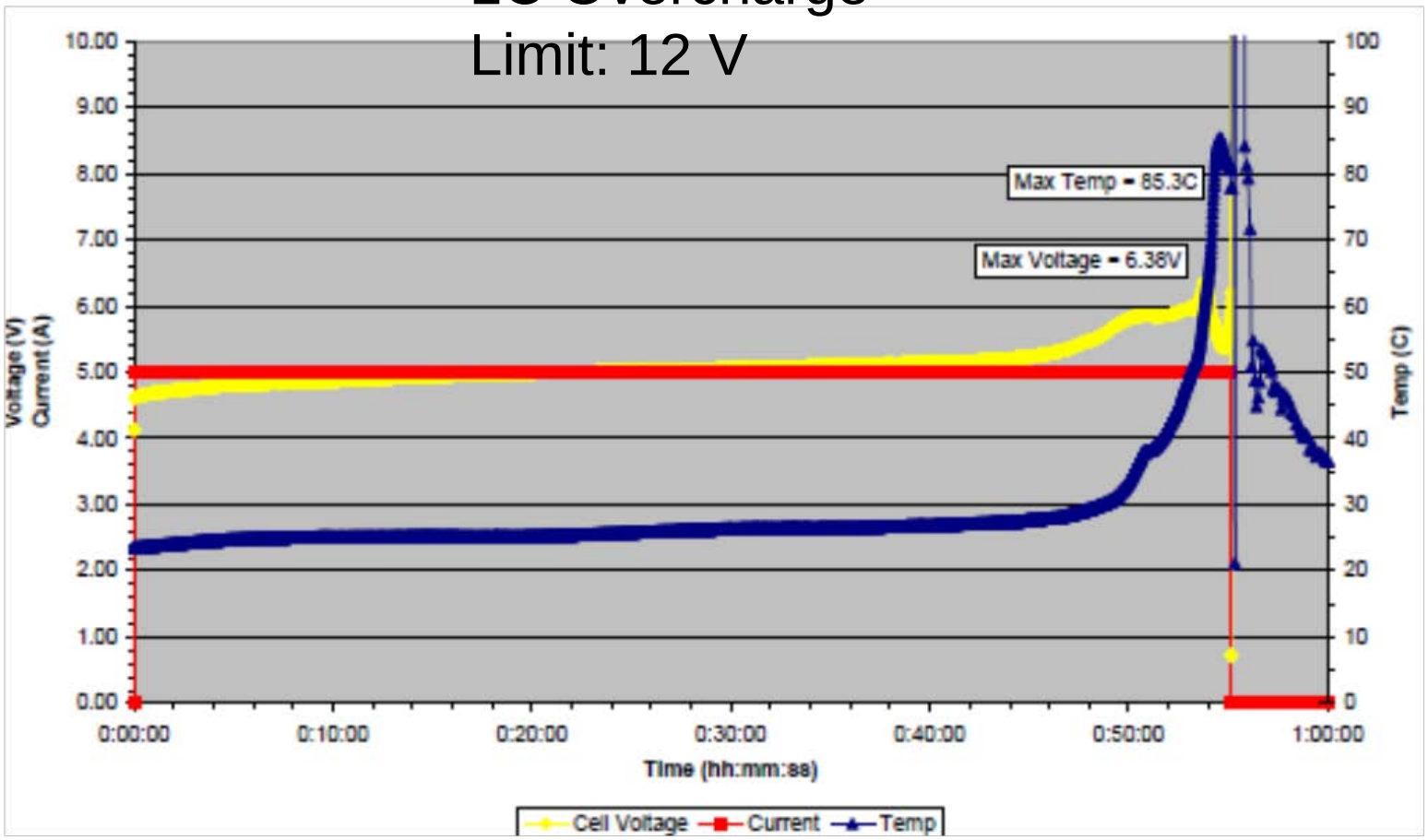


Outside:
Nylon 6 &
with a possible
Acrylic
adhesive

Inside:
Polypropylene

Overcharge Test on Wanma Li-ion Pouch Cell

1C Overcharge
Limit: 12 V

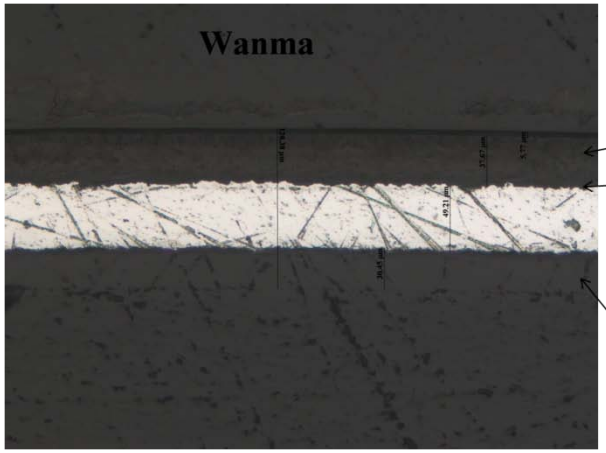


All 3 samples vented violently with fire and thermal runaway

Wanma Li-ion Cell Test Summary

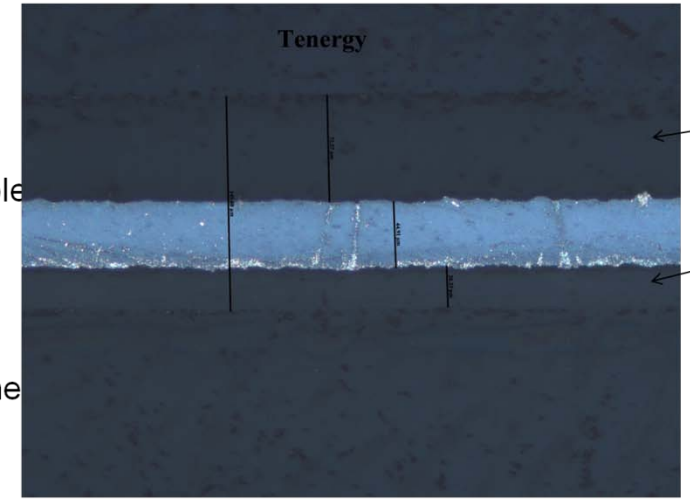
- Although all the tests for the Wanma cells have not been completed, the tests to date show that the cells lose about 16 % capacity after 250 cycles at 1 C rate of discharge.
- The Wanma li-ion cells go into a thermal runaway at 1 C and 0.5 C rates of overcharge.
- The cells lose almost 50 % capacity when cycled in an unrestrained mode under vacuum conditions.

Analysis of Pouch Materials from Different Manufacturers



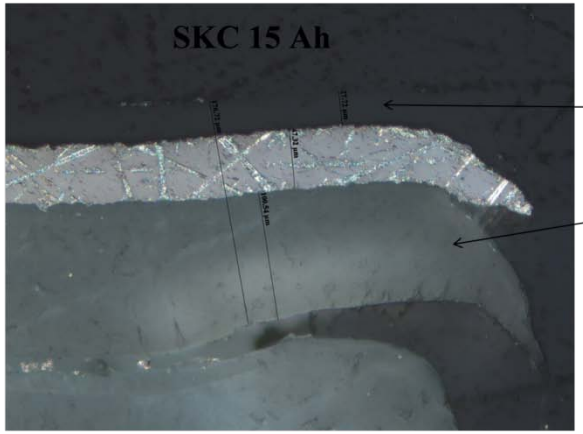
Outside:
Nylon 6 &
with a possible
Acrylic
adhesive

Inside:
Polypropylene



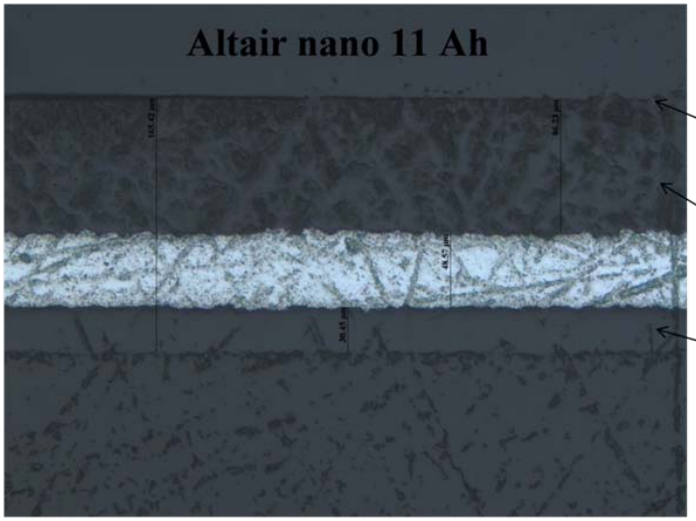
Outside:
Nylon 6

Inside:
Polypropylene



Outside:
Nylon 6

Inside:
Polypropylene



Outside:
Polyethylene
terephthalate &
Nylon 6

Inside:
Polypropylene

Summary

- Lithium-ion Pouch design cells are not true polymer cells
- The li-ion pouch design cells exhibit similar behavior under off-nominal conditions as those in metal cans (that do not have the internal safety devices).
- The li-ion pouch cell designs react most violently to overcharge conditions.
- Some pouch cell designs have higher tolerance to vacuum exposures than some others.
- A comparison of the pouch material itself does not show a correlation between this tolerance and the number of layers or composition of the pouch indicating that this is a property of the electrode stack inside the pouch.
- Reduced vacuum (8 to 10 psi) test environments are currently being carried out and the results will be reported in the near future to determine if there is a higher tolerance to that environment.

Acknowledgment

Test Team Members:

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PC Test

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